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VADOSE ZONE MONITORING SYSTEM DEPLOYMENT (U)

Task 3 Report - Final

Operation and Maintenance Manual

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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1. Introduction

A Vadose Zone Monitoring System (VZMS) was deployed in early 1999 to provide data and information about possible downward flux of water and contaminants emanating from the E-Area Disposal Facility trench area at the Savannah River Site (SRS), which could potentially contaminate ground water. The VZMS consists of monitoring sensors installed in clusters at four depths in each of three boreholes. The sensors measure subsurface conditions including soil water potential, soil water content and pore water concentration. Four other boreholes are equipped with devices that sample soil pore water only. Soil water content and water potential data have been collected continuously from installation through the present, and soil pore water samples were collected periodically.

The sensors used in the VZMS require different levels of active maintenance to ensure proper operation. Several sensors were designed and installed in such as way that active maintenance, specifically because they were permanently installed in the boreholes, and thus are inaccessible. The purposes of this O & M report is to 1) present procedures for wiring and collection of data from sensors used in the VZMS, and 2) present procedures that can be used to check and maintain sensors for better operation.

Therefore, the scope of this report is limited to the specific sensors used in the VZMS. Though some information on sensor characteristics are included, specifications will not be described per se; instead, references or manuals on the sensors, which can assist technical personnel to understand sensor operation, will be referenced when appropriate. Laboratory calibration procedures are contained in a separate (Task 4) report under this contract; however, field calibration procedures, which are used to maintain sensors, will be included herein.

This O & M document will present each procedure as a standalone documents, which can be used exclusively for identifying potential problems and maintaining specific sensors. Each procedure is attached as an appendix. A total of 4 procedures is included: INEEL Advanced

Tensiometers (SOP 2.0), Water Content Reflectometers (SOP 3.0), and Heat Dissipation Sensors (SOP 4.0), and Porous Cup Lysimeters (SOP 5.0). The solution sampler section is very brief given the current existence of a SRS Standard Operating Procedure for the solution sampler (SRS, 1999). Furthermore, though each appendix describes specific programming instructions for interrogating sensors, a full discussion of the program that operates the data logger will be provided in the final, and fifth appendix.

2. References

SRS/WSRC. 1999. Sampling SWMF Lysimeters (U). Procedure #SW 15.1-SOP-LYSI-01, Rev. 1

Appendix 1 -

Operation and Maintenance of INEEL Advanced Tensiometers -

SOP 2.0, v 1.0

STANDARD OPERATING PROCEDURE 2.0

Operation & Maintenance of INEEL Advanced Tensiometer v 1.0

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Operation & Maintenance of INEEL Advanced Tensiometer

1.0 Introduction and Scope of Procedure

The INEEL Advanced Tensiometer (IAT) is used to measure soil water potential in 12 separate locations (Table 2-1), all adjacent to Slit Trench #2 at the E-Area disposal facility. The IATs were fabricated and assembled by Buck Sisson and Joel Hubbell (Hubbell and Sisson, 1998) of the Idaho National Engineering and Environmental Lab (INEEL, Idaho Falls, ID). The IATs consist of several components, some of which were permanently installed in the soil (e.g., the ceramic cup and outer pipe) and others of which are retrievable, including the gasket assembly, pressure transducer and associated wiring.

This section will describe the operation and maintenance procedures for the IAT. It will focus especially on the wiring and use of the pressure transducer mounted inside the IAT, in-field calibration, and the periodic removal of entrapped air inside the cup and water chamber. Fabrication and installation of the IAT is covered in other documents available to SRS personnel.

2.0 Standard Operating Procedures

2.1 Wiring Pressure Transducer to Data Logger

Wires that connect to the pressure transducers must be inserted carefully and into specific ports of the data logger. The ports to be used depend solely on locations specified by the user in the data logger program. Therefore, it is important that the program be available to the field personnel while the loggers are being wired, or the field personnel should be familiar with the data logger program to be able to search the program for the correct instruction. The pressure transducers used in the VZMS monitoring program have four electrical leads. The wires brought to ground surface are colored to make identification and wiring easier.

Table 2-1 ID numbers and locations for Advanced Tensiometers

Logger ID	Sensor ID	Depth	Location
		------ m (ft) -----	
5	5-AT-1-22	6.7 (22)	E of slit trench #1
5	5-AT-2-32	9.8 (32)	E of slit trench #1
5	5-AT-3-41	12.5 (41)	E of slit trench #1
5	5-AT-4-55	16.8 (55)	E of slit trench #1
6	6-AT-1-23	7.0 (23)	E of slit trench #1
6	6-AT-2-30	9.2 (30)	E of slit trench #1
6	6-AT-3-41	12.5 (41)	E of slit trench #1
6	6-AT-4-55	16.8 (55)	E of slit trench #1
7	7-AT-1-11	3.4 (11)	N of slit trench #1
7	7-AT-2-22	6.7 (22)	N of slit trench #1
7	7-AT-3-41	12.5 (41)	N of slit trench #1
7	7-AT-4-53	16.2 (53)	N of slit trench #1

Material:

1. Hard (paper) copy of data logger program which specifies the location of transducer wires.
2. Flat head screwdriver. It is recommended to use the tool that accompanied the data. logger.
3. Needle-nosed pliers

Methods:

1. Strip ends of each wire leaving 8 mm (1/4 inch) of bare wire.
2. Insert the target wire into the terminal port (Figure 2-1 is a schematic of the 23X data logger).

3. Secure the wire to the terminal port using a flat head screwdriver.
4. Check the connection by gently pulling on the transducer wire.
5. Continue with the next wire until all are secure.

Color schemes and locations for transducer wires are as follows:

Color	Port Location
Red	Excitation port
Black	Ground
White	High (H) side of differential port
Green	Low (L) side of differential port

In some cases, more than one excitation and ground wire will be assigned to a single terminal port. The data logger is able to source current to approximately seven transducers (of the type used herein), from a single excitation port without damaging the data logger. No limit exists on the number of ground wires that can be used in a single ground port; however, inserting more than four wires in a single terminal port can be challenging.

2.2 Initial Filling of Water

After ceramic cup and outer pipe are installed in the borehole, the ceramic material must be filled with water prior to collection of meaningful soil water potential data. The procedures are similar to those taken during routine maintenance, but are included below for completeness.

Material:

1. Log book
2. Beaker or flask
3. Tap water

Methods:

1. Connect the pressure transducer wires to the data logger, as described in Section 2.2.1.
2. Raise the inner guide pipe (1.25 cm (1/2 inch) polyethylene) approximately 2.5 cm (1 inch).
3. Using a container of water (i.e., beaker or squeeze bottle), pour ~100 ml between the outside of the inner guide pipe and the inside of the outer guide pipe (Figure 2-2) so that the porous ceramic cup is filled with water. The source of water should be de-aired if possible.
4. Carefully lower the inner guide pipe so that the gasket seats into the gasket throat. The inner guide pipe should fit snugly in the throat so that a vacuum-tight seal can be achieved.
5. Check the data logger readings to see whether the transducer/logger system is working. Specifically, if the voltage readings show either 0.000 or -99999, then it is likely that wiring problem is occurring, with the former case indicating that no excitation of the transducer occurred, and the latter indicating that either of the differential wires was not connected properly. Recheck the wiring to be sure that it is correct.

2.3 Removing Air in Tensiometer Cup

Air dissolution through the cup material will occur, thus requiring on-going maintenance to remove the air accumulation.

Material:

1. Log book
2. Beaker or flask (~200 ml)
3. Tap water

Methods:

1. Check pressure transducer reading to get initial conditions prior to degassing the

tensiometer cup.

2. Raise the pressure sensor gasket assembly 2.5 cm (1 inch) to allow air to escape and water to fill the cup and water chamber.
3. Check the pressure transducer data on the logger. The presence of an adequate volume of water in the cup can be verified by a positive pressure being observed when the pressure transducer is raised a few cm above the adapter.
4. Using a container of water (i.e., beaker or squeeze bottle), pour ~50 ml between the outside of the inner guide pipe and the inside of the outer guide pipe (Figure 2-2). If the space above the gasket is completely dry, 50 ml of water should correspond to ~13 cm of water height. The source of water should be de-aired if possible.
5. Lower the gasket assembly on the gasket. Positive pressure will be observed for a short period of time, because water is being forced out of the water chamber. This positive pressure should dissipate quickly.

No specific schedule for servicing tensiometers is listed here because degassing needs vary depending on many variables; however, it is recommended that all tensiometers be serviced every six (6) months or less. It is important to note, though, that the tensiometer will continue to function properly even when some air bubbles exist inside the cup and chamber. However, the response time of the tensiometer to changes in soil water potential will increase dramatically because water will move relatively slowly through the cup wall, rather than kinematic pressure changes that move quickly. Nevertheless, if the soil water conditions are not changing appreciably, or are changing gradually, the tensiometer will still provide accurate data.

2.4 In-field Calibration

With the exception of manometers, virtually all gauges require some level of calibration, either performed at the factory or by the end user. Pressure transducers used on the IATs (model 26PCCFA1D, Honeywell MicroSwitch, Freeport, IL) require calibration so that electrical responses can be related to physical changes in the environment. They were calibrated in the

laboratory prior to field installation, but some shifts in either the offset or slope of the calibration curve could result in a systematic bias in the soil water potential data after some time period. Therefore, field checking the calibration curve provides additional information on potential drift or transducer failure, without disassembling the IAT and returning the transducer to the laboratory.

Materials:

1. Hand-held pressure sensor (e.g., Tensimeter®, Soil Measurement Systems, Tucson, AZ).
2. T-valve with septum stopper on one side, and connectors on remaining two sides.
3. Hand-held pump
4. Log book or data sheet

Methods:

1. Zero the hand-held gauge (referred to as a Tensimeter).
2. Disconnect the desiccator tubing from the vent line of the transducer.
3. Attach the open end of a T-valve to the appropriately labeled vent tubing on the pressure transducer (Figure 2-3).
4. Raise the inner guide pipe above the gasket (see Figure 2-2), so that the sensing port is above the water level in the stand pipe; this provides the atmospheric pressure needed on one side of the sensor.
5. Check to be sure the Tensimeter reading is zero, and reset if not. Record the zero offset.
6. Attach the Tensimeter to the T-valve by puncturing the septum stopper, labeled accordingly, with the needle of the Tensimeter (follow safety instructions that accompanied the Tensimeter) and check Marthaler et al. (1983) for further information.
7. Connect the hand pump to the last available port on the T-valve. The Tensimeter is now pneumatically connected to the hand pump and reference port of the pressure transducer.
8. Apply a range of pressures to the reference port. Choose a series of increasing pressure steps, similar but opposite to those listed for laboratory calibration (e.g., 5, 10, 25, 50, 75,

100, 200, and 500 mbar (~ cm H_2O)). Note that positive pressure applied to the reference port is the same as vacuum applied to the stopper end of the gasket assembly.

9. Allow the Tensimeter to equilibrate between each pressure step and record the Tensimeter readings into a log book or calibration sheet. Equilibration should be achieved within 10 seconds. A very slow response indicates that the needle of the Tensimeter is clogged with debris and should be cleaned.
10. Check the data logger and write down the voltage reading.
11. Repeat steps 8 - 10 until all pressure steps have been checked.
12. When calibration is completed, lower the inner guide pipe so that it seats properly on the gasket, disconnect the T-valve from the vent tube, and reconnect the desiccator tubing.
13. Using either a spreadsheet program or some other program capable of performing simple linear regression, manually type in the pressure readings measured with the Tensimeter into the table using the values as the dependent variable, and the data logger voltage measurements as the independent variable.
14. Regress the voltage reading from the transducer onto the pressure measured with the Tensimeter.
15. Check the coefficient of determination (r^2) to see that the calculated value exceeds a user-specified criteria (e.g., $r^2 > 0.999$).
16. Record the new calibration parameters into whatever data management package is used for reducing and archiving the VZMS data.

3.0 Other Relevant Issues

3.1 Data Logger Instruction for Pressure Transducer Interrogation

Campbell Scientific, Inc. uses P-instructions for interrogating pressure transducers. The instruction specifies the excitation port, resolution of the analog (voltage)/digital conversion, output location for the reading, and calibration parameter (if chosen). Using PC208W software to program the data logger, the P-instruction is specified as:

1: Full Bridge (P6)	CSI P-instruction number
1: 1 Reps	One excitation per instruction
2: 15 5000 mV, Fast Range	Highest voltage output will be converted to digital value
3: 1 DIFF Channel	Specified differential channel on data logger front panel
4: 1 Excite all reps w/Exchan 1	Specified excitation channel on data logger front panel
5: 5000 mV Excitation	Magnitude of voltage excitation
6: 1 Loc [pt]	Output location
7: 1.0 Mult	Slope of calibration curve (1.0 is default)
8: 0.0 Offset	Offset of calibration curve (0.0 is default)

The above P6 instruction specifies a single, 5000 mv excitation of a full (wheatstone bridge) from Exc port #1, with an analog/digital conversion from differential port #1. Digital output is transferred to location #1 (called pt). Using a slope = 1.0 and offset = 0.0, provides a raw voltage output reading. The data can be converted to soil water potential in either a spreadsheet program or the VZMS Database Manager, which was designed to manage and archive VZMS data. Figure 2-1 indicates the locations of the transducer leads using the above P instruction.

3.2 Schedule for Field Calibration of Pressure Transducers

No rules exists for specifying when or how often in-field calibration of pressure transducers should be performed. The transducers used on the IATs are protected from most environmental conditions that could lead to reduced lifespan, especially diurnal temperature fluctuations. Thus, the transducers could last a considerably long period of time without failure. Results described by Young (2000) indicate that data from the IAT are stable with no apparent drift, even after nine months of continuous use. Nevertheless, it would advisable to perform an in-field calibration approximately every six months and archive the old calibration parameters, so that the user can determine whether the parameters are drifting significantly. The results could be useful for identifying failing sensors.

3.3 Equilibration of Potential

Whenever servicing the transducers (either calibrating or degassing) it is important to monitor potentials before and after the system is disturbed. Several days may be needed for the tensiometer to come into equilibrium with the water potential of the soil, especially if the soil is dry. However, if several days pass without any change in the readings, or if the readings are close to the offset value of the calibration curve, it is possible that a vacuum leak is present and the gasket assembly should be reseated. Technical personnel should monitor the soil water potential readings carefully for several days after servicing or reseating the gasket assembly until the readings approach pre-disturbance conditions.

3.4 Need for Desiccant

IATs are equipped with a desiccant chamber, which is attached to the vent line of the transducer. The desiccant ensures that water does not build up in the vent line, potentially causing 1) water to bridge the vent line, biasing the readings, 2) water to run down the vent line, contact the electronics of the transducer, and short it out, 3) otherwise corrode the transducer wires. The desiccant (CSI, model DSC20/4) needs to be checked periodically to ensure that the material is not saturated, otherwise it will no longer absorb water from air. When this happens, the material can be serviced by placing it in a drying oven so that the water is evaporated. Often, color changes of the desiccant material signals the need for servicing.

4.0 References

Hubbell, J.M., J.B. Sisson. 1998. Advanced tensiometer for shallow or deep soil water potential. Soil Sci. 163(4):271-77.

Marthaler, H.P., W. Vogelsanger, F. Richard, P.J. Wierenga. 1983. A pressure transducer for field tensiometers. Soil Sci. Soc. Am. J. 47(3):624-27.

Young, M.H. 2000. Task 5 Report - Evaluation of Data from the Vadose Zone Monitoring System: E-Area Disposal Facility. Submitted under Contract No.: KE56201-0-GA0052, ERDA/SRS.

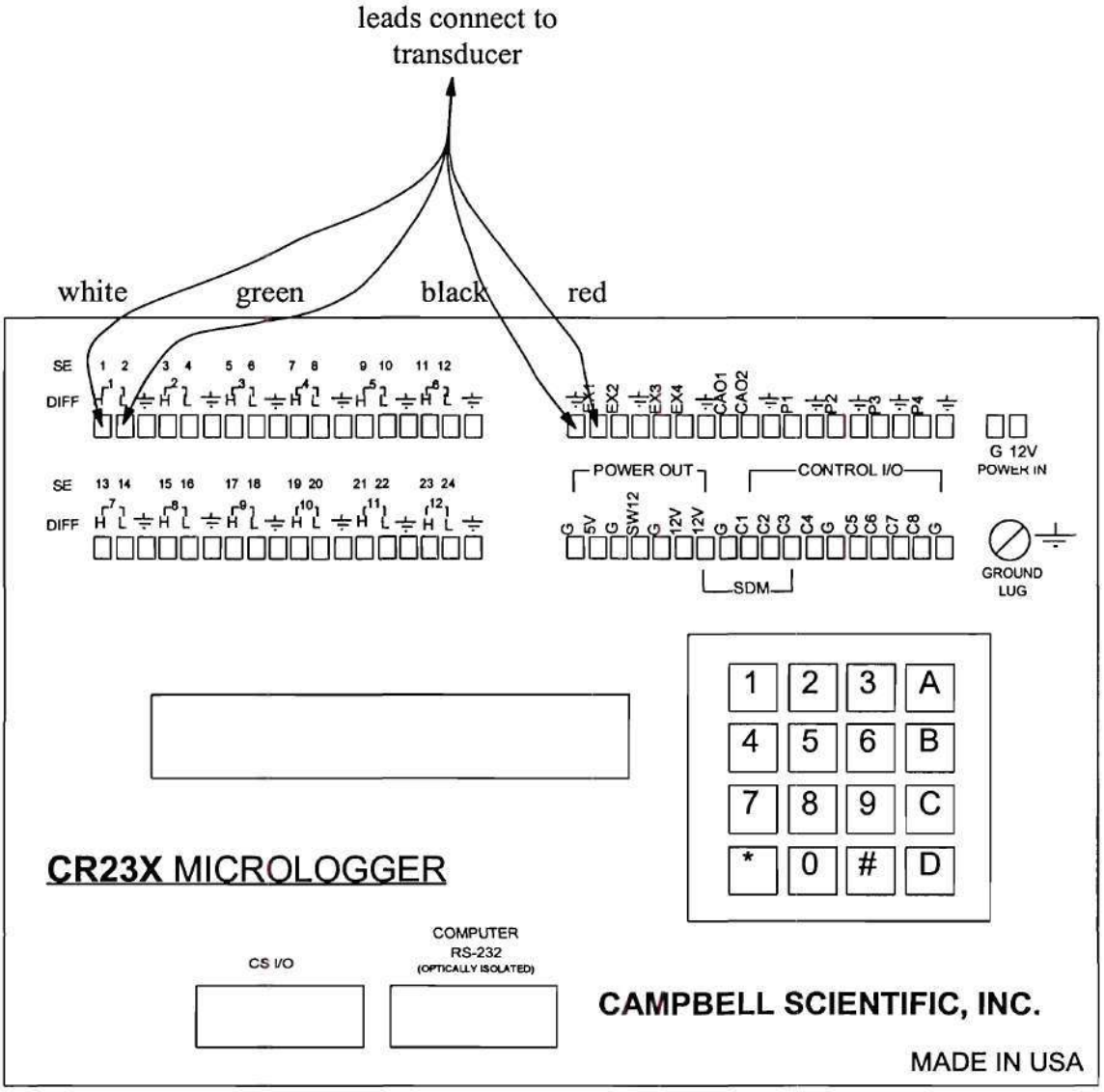

Figure 2-1 Schematic of Campbell Scientific CR-23X datalogger and transducer wiring.

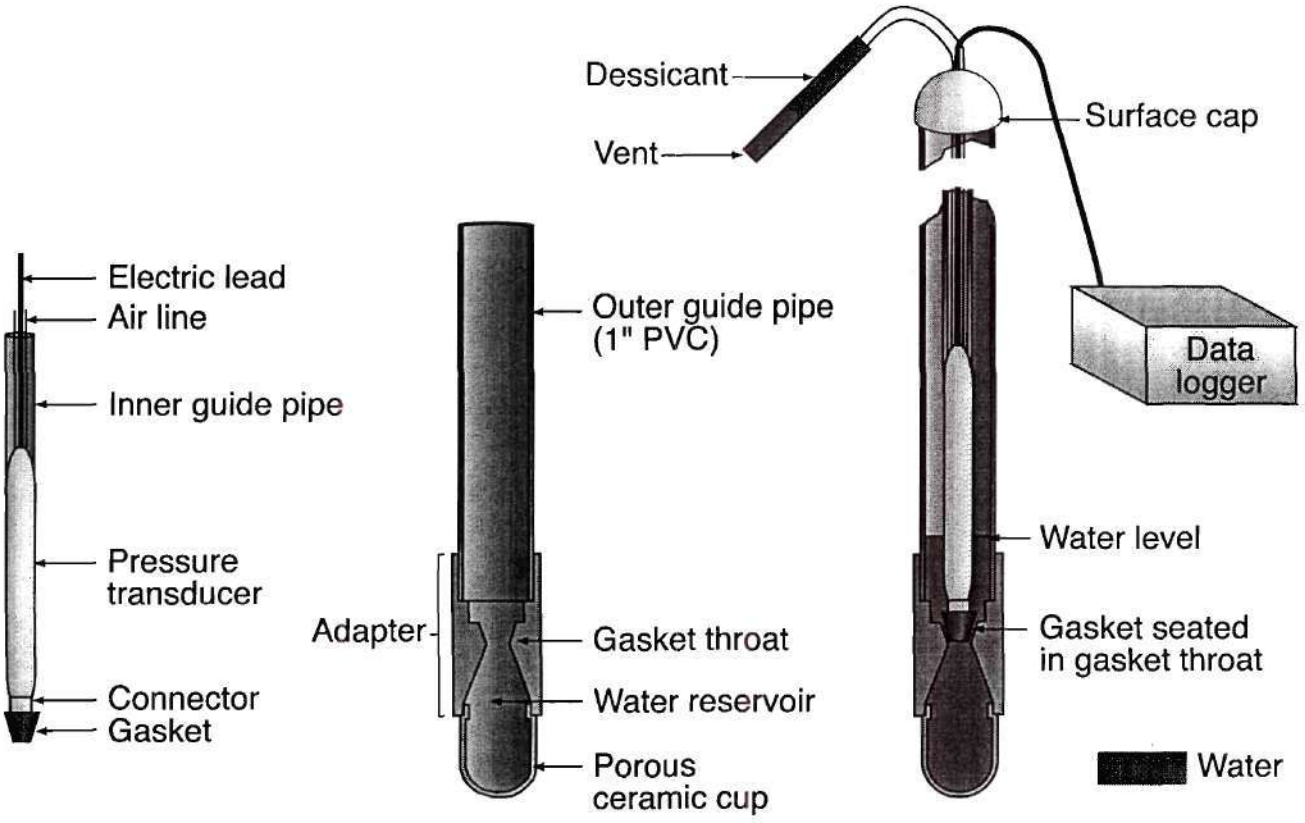

Figure 2-2 Schematic of INEEL Advanced Tensiometer (after Hubbell and Sisson, 1996).

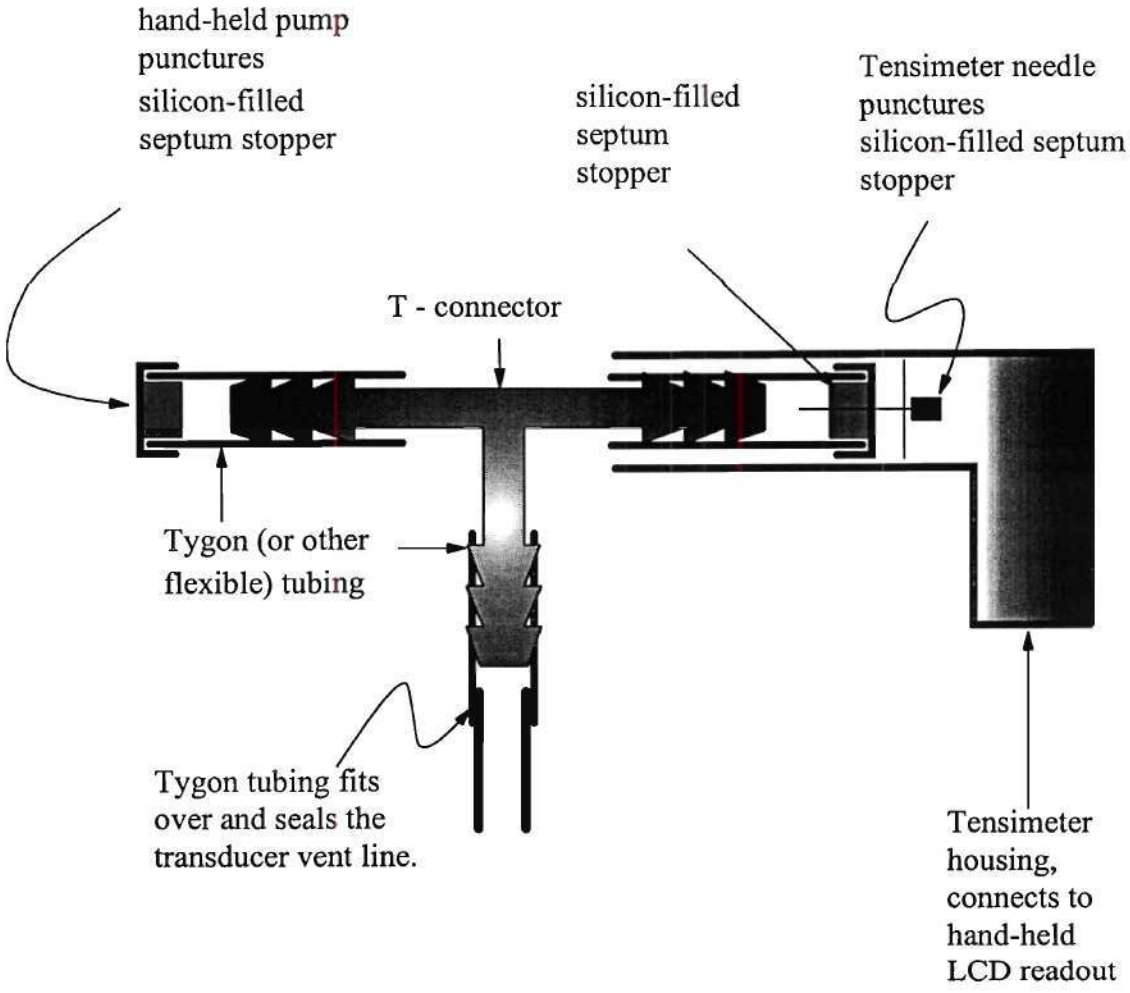

Figure 2-3 Schematic of in-field calibration setup.

Appendix 2 -

Operation and Maintenance of Water Content Reflectometers - SOP 3.0, v 1.0

STANDARD OPERATING PROCEDURE 3.0

Operation & Maintenance of Water Content Reflectometers
v 1.0

Contract No.: KE56201-0-GA0052
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The Water Content Reflectometer (WCR; model CS 505-L, Campbell Scientific, Inc., Logan, UT) is used to measure soil water content in three boreholes at four depths in each borehole (Table 3-1). They are located adjacent to Slit Trench #2 at the E-Area disposal facility. The WCR sensors were fabricated at CSI and are fully contained units; however, they have been modified to place in the boreholes. The WCR does not require any active maintenance, though the electrical leads should be protected from corrosion. Laboratory calibration, which is needed to ensure more accurate water content values, is discussed in Young (2000). These sensors cannot be recalibrated in the field after installation.

This section will describe the operation and maintenance procedures for the WCR. It will focus on wiring to and the interrogation from the data logger. Fabrication and installation of the WCR is covered in other documents available to SRS personnel (e.g., Wyatt et al., 1999).

2.0 Standard Operating Procedures

2.1 Wiring Water Content Reflectometer to Data Logger

Wires that connect to the WCR must be inserted carefully and into specific terminal ports of the data logger. The ports to be used depend solely on locations specified by the user in the data logger program. Therefore, it is important that the program be available to the field personnel while the loggers are being wired, or the field personnel should be familiar with the data logger program to be able to search the program for the correct instruction. The WCR sensors used in the VZMS monitoring program have five electrical leads. The wires brought to ground surface are colored to make identification and wiring easier.

Table 3-1 ID numbers and locations for Water Content Reflectometers

Logger ID	Sensor ID	Depth	Location
		------ m (ft) -----	
5	5-WC-1-22	6.7 (22)	E of slit trench #1
5	5-WC-2-32	9.8 (32)	E of slit trench #1
5	5-WC-3-41	12.5 (41)	E of slit trench #1
5	5-WC-4-55	16.8 (55)	E of slit trench #1
6	6-WC-1-23	7.0 (23)	E of slit trench #1
6	6-WC-2-30	9.2 (30)	E of slit trench #1
6	6-WC-3-41	12.5 (41)	E of slit trench #1
6	6-WC-4-55	16.8 (55)	E of slit trench #1
7	7-WC-1-11	3.4 (11)	N of slit trench #1
7	7-WC-2-22	6.7 (22)	N of slit trench #1
7	7-WC-3-41	12.5 (41)	N of slit trench #1
7	7-WC-4-53	16.2 (53)	N of slit trench #1

Material:

1. Hard (paper) copy of data logger program which specifies the location of WCR leads.
2. Flat head screwdriver. It is recommended to use the tool that accompanied the data logger.
3. Needle-nosed pliers.

Methods:

1. Strip ends of each wire leaving 8 mm (1/4 inch) of bare wire (unless already done by the manufacturer).
2. Use needle-nosed pliers to grab the target wire and insert into the terminal port (Figure 3-1 is a schematic of the 23X data logger).

3. Secure the wire to the terminal port using a flat head screwdriver.
4. Check the connection by gently pulling on the transducer wire.
5. Continue with the next wire until all are secure.

Color schemes and locations for WCR leads are as follows:

Color	Port Location
Red	12 Vdc
Orange	Control port
Black	Ground
Clear	Shield (ground)
Green	Analog input or pulse channel

In some cases, more than one 12 vdc and/or ground wire will be inserted into a single terminal port. The data logger is able to supply the voltage requirements from the 12 vdc terminal port for several WCR sensors without damaging the data logger. No limit exists on the number of ground wires that can be used in a single ground port; however, inserting more than four wires in a single terminal port can be challenging.

3.0 Other Relevant Issues

3.1 Data Logger Instructions for WCR Interrogation

Campbell Scientific, Inc. uses two possible P-instructions for interrogating WCR sensors. Both are described below. However, the VZMS program uses only the period averaging technique. Each instruction specifies the location of the excitation port, resolution of the analog (voltage)/digital conversion, output location for the reading, and calibration parameters (if chosen). Resolution of the water content values differ depending on the P instruction. Resolution using the P27 instruction (Section 3.3.1.a) is 10^{-6} m^3/m^3, and resolution using the P3 instruction (Section 3.3.1.b) is 10^{-4} m^3/m^3 using a 1.0 second time interval. Using the PC208W

software to program the data logger, the sets of P-instructions are described below.

3.1.1 Interrogation of WCR using period averaging

This first instruction (P27) measures the period (in units of msec) that it takes for a voltage pulse to travel to the probe end and back. The reflected voltage that exceeds ±2.5 vdc is used as the criteria for pulse arrival. Shorter travel times indicate lower soil dielectric constants, and hence lower water contents. A total of five instructions are listed below in Table 3-2. The fourth instruction collects the period data, and the other four instructions prepare the sensor electronics.

The P27 instruction set results in a single reading from a WCR sensor, connected to control port #5 (Figure 3-1A), with the single-ended analog port #1 to measure voltage response. A total of 5 cycles are to be counted from the logger (averaging the travel time of each cycle) with a delay of 1.00 seconds. Digital output is transferred to Location #1 (called theta). The highest frequency (or shortest travel time) that can be resolved by the data logger was chosen as 200 Hz, or 5 msec. Using a slope = 1.0 and offset = 0.0 provides an output in time

3.1.2 Interrogation of WCR using pulse counting

The second method of interrogating the WCR is to use the pulse counting channel, normally used for paddle wheel flow meters, tipping bucket rain gauges, etc. The P3 instruction counts the number of frequency of a voltage pulse that rises above the ±2.5 vdc threshold within a specific amount of time, which is normally the excitation interval. More peaks per time period indicate higher frequencies and, therefore, lower water contents. Table 3-3 shows that only the fourth instruction is used for counting the peaks, and the others are used for preparing the sensor.

The P3 instruction states that counting occurs in pulse channel #1 (Figure 3-1B), with the output converted to frequency (250 kHz maximum). Using a slope = 1.0 and offset = 0.0 provides an output in frequency. The data can be converted to soil water content using the laboratory calibration parameters in either a spreadsheet program or the VZMS Database Manager, which was designed to manage and archive VZMS data.

Table 3-2 Campbell Scientific, Inc. instructions for WCR interrogation using period averaging.

Set Port (P20)		
1: 1	Set High	Turn on voltage
2: 5	Port Number	to control port #5
Beginning of Loop (P87)		
1: 1	Delay	Delay the program for 2 x 1 second to stabilize control port
2: 2	Loop Count	and WCR sensor
End (P95)		End delay
Period Average (SE) (P27)		
1: 1	Reps	One excitation per instruction
2: 04	200 kHz Max Freq @ 500 mV P-to-P, Period Output	Highest frequency resolved by logger is 200 Hz; output is in units of time.
3: 1	SE Channel	Specified single-ended channel on data logger front panel
4: 5	No. of Cycles	Number of cycles to be measured by logger
5: 100	Timeout (units = 0.01 seconds)	Time delay so that cycles can be measured
6: 1	Loc [theta]	Output location
7: 1.0	Mult	Slope of calibration curve (1.0 is default)
8: 0.0	Offset	Offset of calibration curve (0.0 is default)
Set Port (P20)		
1: 0	Set Low	Turn voltage off at
2: 5	Port Number	Control port #5

3.2 Need for Desiccant

Desiccant material is normally stored inside the environmental enclosure which houses the data logger and the unshielded leads from the WCR and other sensors. The desiccant (CSI, model DSC20/4) reduces the humidity level so that corrosion is minimized. Each logger box has a color indicator for humidity. The desiccant will no longer absorb water from air when humidity level is too high. However, material can be serviced by placing it in a drying oven so that the water evaporates.

Table 3-3 Campbell Scientific, Inc. instructions for WCR interrogation using pulse counting.

Set Port (P20)		
1: 1	Set High	Turn on voltage
2: 5	Port Number	to control port #5
Beginning of Loop (P87)		
1: 1	Delay	Delay the program for 2 x 1 second to stabilize control port
2: 2	Loop Count	and WCR sensor
End (P95)		End delay
Pulse (P3)		
1: 1	Reps	One excitation per instruction
2: 1	Pulse Input Channel	Specified pulse input channel on data logger front panel
3: 21	Low Level AC, Output Hz	Conversion of A/C (periodic) signal to frequency
4: 2	Loc [theta]	Output location
5: 1.0	Mult	Slope of calibration curve (1.0 is default)
6: 0.0	Offset	Offset of calibration curve (0.0 is default)
Set Port (P20)		
1: 0	Set Low	Turn voltage off at
2: 5	Port Number	control port #5

4.0 References

Wyatt, D., D. Stephanson, B. Looney, J. Rosabi, J. Cook, H. Holmes-Burns, B. Sisson. 1999. E-Area Vadose Zone Proposed Plan (U). Report WSRC-RP-99-4039, Rev. 0.

Young, M.H. 2000. Task 4 Report - Calibration Manual. Submitted under Contract No.: KE56201-0-GA0052, Vadose Zone Monitoring System Deployment (U). ERDA/SRS.

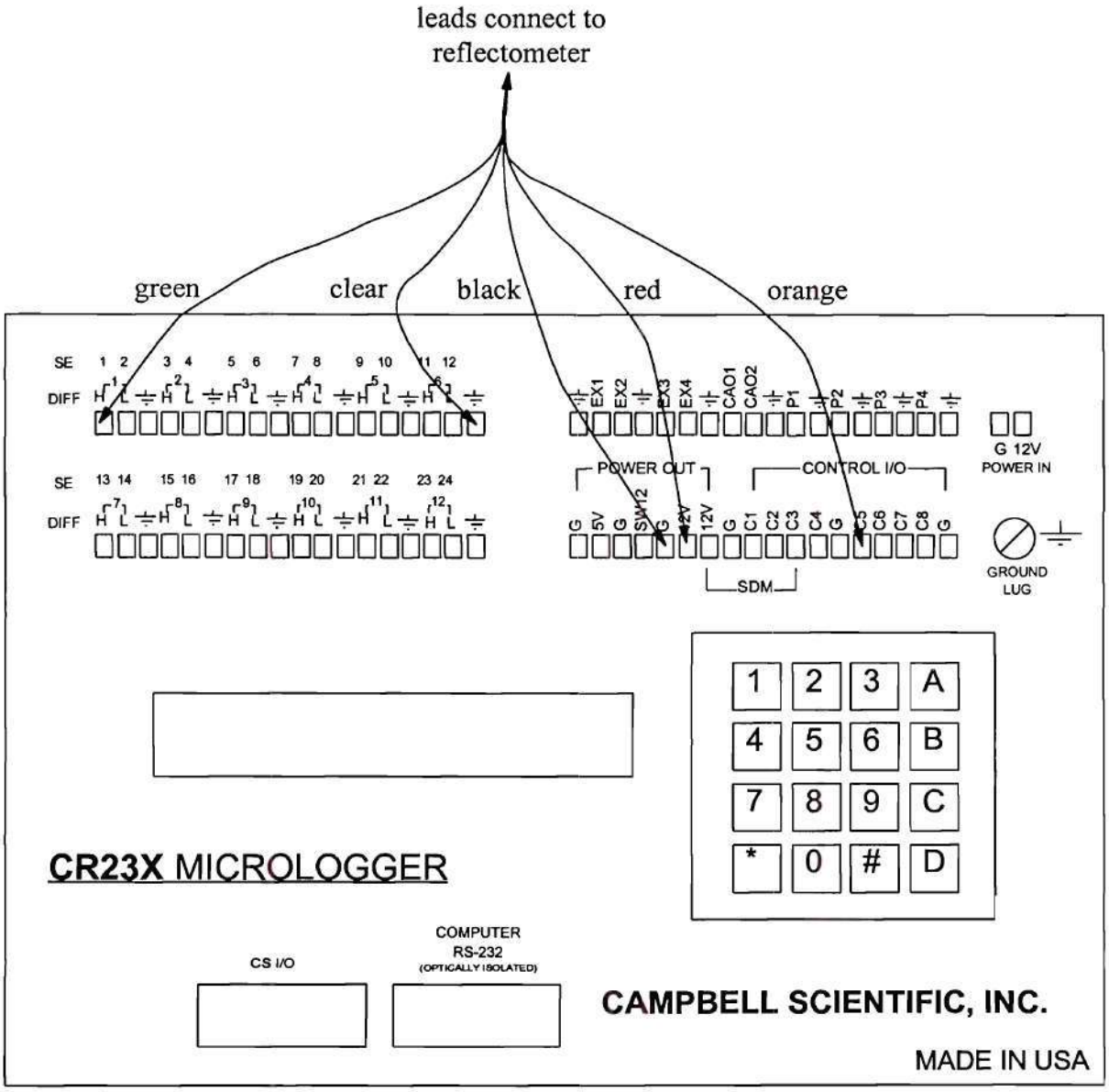
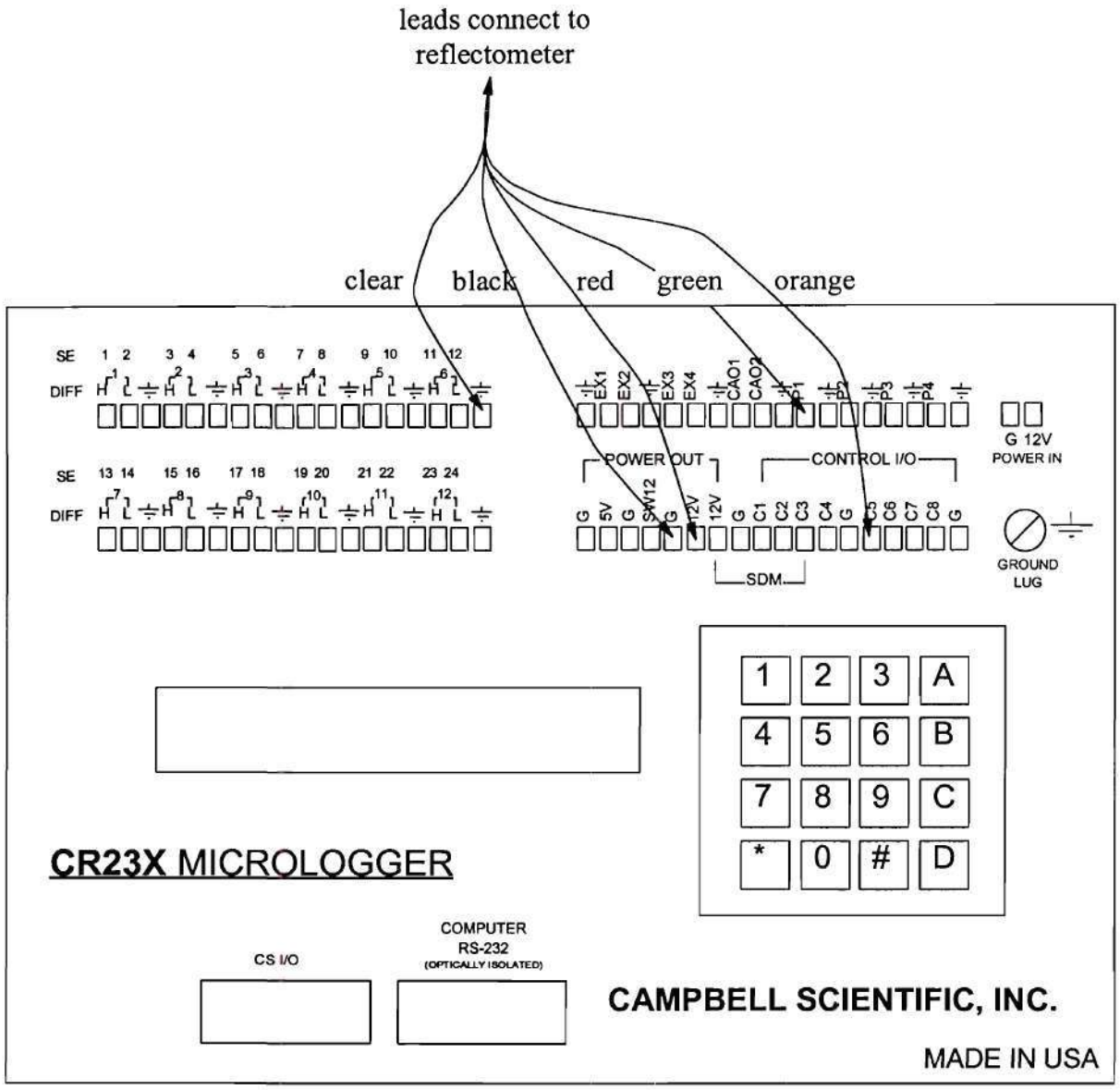


Figure 3-1A Schematic of Campbell Scientific CR-23X datalogger, with associated wiring requirements for period averaging, corresponding to Table 3-2.



3-1B Schematic of Campbell Scientific CR-23X datalogger, with associated wiring requirements for pulse counting, corresponding to Table 3-3.

Appendix 3 -

Operation and Maintenance of Heat Dissipation Sensors -

SOP 4.0, v 1.0

STANDARD OPERATING PROCEDURE 4.0

Operation & Maintenance of Heat Dissipation Sensors
v 1.0

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

Prepared by:

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Prepared for:

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Revision 1: Developed by: _____ Date: _____
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Approved by: _____ Date: _____

Revision 3: Developed by: _____ Date: _____
Reviewed by: _____ Date: _____
Approved by: _____ Date: _____

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1.0 Introduction and Scope of Procedure

The Heat Dissipation Sensors (HDS, model 229, Campbell Scientific, Inc., Logan, UT) are planned for use in the Mega-Trench site; no HDS are used at the Slit Trenches at the E-Area disposal facility. The HDS sensors, also referred to as Soil Water Potential Probes, are fabricated at CSI and are fully contained units. The HDS does not require any active maintenance, though the electrical leads should be protected from corrosion. Laboratory calibration, which is required to ensure more accurate soil water potential values, is discussed in Young (2000). These sensors cannot be recalibrated in the field after installation.

This section will provide a brief background on the HDS, then describe the operation and maintenance procedures. It will focus on wiring to and the interrogation from the data logger.

1.1 Brief Background on Heat Dissipation Sensors

The HDS consists of a heating element and temperature thermocouple, both surrounded by a rod-shaped, porous ceramic material. The heating element is connected to a constant current interface which provides 50 milliamps ± 0.25 milliamp of current. The current causes heat to build up along the heating element. The change in heat is then recorded using the thermocouple. Movement of thermal energy away from the heating element and toward the thermocouple depends on the thermal conductivity of the ceramic, and the thermal conductivity, in turn, depends on the water content of the ceramic. Higher water content causes higher thermal conductivity. The magnitude of the temperature increase recorded by the thermocouple will be less in wetter material because conduction causes greater dissipation of heat.

Because the ceramic is porous and in contact with the soil, water will flow toward or away from the ceramic, depending on the potential energy differences between the soil and ceramic. If the

ceramic material is drier than the soil, it will absorb water until the potential differences are negligible, and vice versa.

The Campbell data logger controls the constant current interface (model CE-8) using one of the digital control ports. When the control port is set high, the constant current interface energizes the heating element. The data logger is then instructed to measure the thermocouple temperature after two time delays, usually after one second, and then again after usually 20-25 sec. The difference in recorded temperatures is known as the ΔT. After measuring the ΔT, the current excitation at the heating element ceases. Calibration research on the HDS (Reese, 1996) has confirmed that the natural log of the soil water potential is linearly related to ΔT, using:

$$\ln(|\psi|) = \alpha \Delta T + \beta \quad (4\text{-}1)$$

where ψ is the soil water potential, α is the calibration slope, and β is the offset. The operational range of the HDS is influenced, in part, by the resolution of the data logger to measure very small changes in temperature. Data loggers with higher analog/digital conversion rates are able to detect smaller changes in temperature. The upper limit of the operational range, therefore, is limited by the soil wetness, usually corresponding to a soil water potential of -100 cm of H_2O (CSI, 1999), though Young et al. (1999) was able to calibrate the sensor to a soil water potential of -50 cm H_2O). Very dry soils with potentials less than several hundred bar are still measurable with the HDS (D. Levitt, Bechtel Nevada, personal communication, 2000).

2.0 Standard Operating Procedures

2.1 Wiring Heat Dissipation Sensors to Data Logger

Operational wiring requirements include connecting the CE8 interface to the data logger, and the HDS to both the interface and logger. The HDS sensors have four electrical leads and the wires brought to ground surface are colored to make identification and wiring easier. Wires that

connect to the HDS must be inserted carefully and into specific terminal ports of the data logger and interface. The ports to be used depend solely on locations specified by the user in the data logger program. Therefore, it is important that the program be available to the field personnel while the loggers are being wired, or the field personnel should be familiar with the data logger program to be able to search the program for the correct instruction.

Material:

1. Hard (paper) copy of data logger program which specifies the location of HDS leads.
2. Flat head screwdriver. It is recommended to use the tool that accompanied the data logger.
3. Needle-nosed pliers.

Methods:

1. Strip the ends of each wire leaving 8 mm (1/4 inch) of bare wire (unless already done by the manufacturer).
2. Use needle-nosed pliers to grab the target wire and insert into the terminal port (Figure 4-1 is a schematic of the 23X data logger).
3. Secure the wire to the terminal port using a flat head screwdriver.
4. Check the connection by gently pulling on the transducer wire.
5. Continue with the next wire until all are secure.
6. Continue wiring the CE8 interface, following the schematic in Figure 4-1.

The CE8 interface, which can source current to eight HDS simultaneously, is controlled using one of the digital control ports on the data logger. Wiring colors are not included for the connections between the logger and CE8 interface. The user should choose unique colors and label the wires accordingly.

Color schemes and locations for HDS leads are as follows:

Color	Port Location / Device
Red	High (H) side of diff port/Logger
Blue	Low (L) side of diff port/Logger
Black	High (H) port/CE8 interface
Green	Low (L) port/CE8 interface

3.0 Other Relevant Issues

3.1 Data Logger Instructions for HDS Interrogation

Campbell Scientific, Inc. uses P-instructions for interrogating HDS sensors. The set of instructions specifies the location of the excitation and digital control ports, resolution of the analog (voltage)/digital conversion, output location for the reading, and calibration parameters (if chosen). Using the PC208W software to program the data logger, the sets of P-instructions that interrogate the HDS are described below.

The set of instructions for interrogating the HDS is listed in Table 4-1. Explanations accompany each instruction. Note that temperature measurements are made three times: 1) ambient temperature used as a reference, 2) initial temperature at the HDS sensor, 3) final temperature after 20 seconds of current heating. The second and third temperature measurements are used for determining ΔT, and the P35 instruction calculates the ΔT value. Instructions for initiating and stopping the current heating surround the final measurement. Note that the integration range (parameter #2) in the temperature measurement can be increased if the temperature is too high for accurate conversion to digital value. The final ΔT value is then used in a calibration curve, as shown in Equation 4-1.

3.2 Need for Desiccant

Table 4-1 Campbell Scientific, Inc. instructions for HDS interrogation.

Panel Temperature (P17)		
1: 1	Loc [panel]	Obtain reference temperature
Thermocouple Temp (DIFF) (P14)		
1: 1	Reps	Measure single thermocouple
2: 21	10 mV, 60 Hz Reject, Slow Range	Integration range
3: 1	DIFF Channel	Measure on Different channel #1on 23x panel
4: 1	Type T (Copper-Constantan)	Thermoucouple type in HDS
5: 1	Ref Temp (Deg. C) Loc [panel]	Location of reference temperature
6: 2	Loc [temp1]	Output location for initial temperature
7: 1.0	Mult	Slope of calibration curve (1.0 is default)
8: 0.0	Offset	Offset of calibration curve (0.0 is default)
3: Do (P86)		
1: 41	Set Port 1 High	Turn on CE8 interface, begin current excitation
Beginning of Loop (P87)		
1: 1	Delay	Delay the program for 2 x 1 second to stabilize
2: 1	Loop Count	HDS sensor
End (P95)		End delay
Beginning of Loop (P87)		
1: 1	Delay	Delay the program for 20 x 1 second to allow
2: 20	Loop Count	temperature dissipation to occur.
Thermocouple Temp (DIFF) (P14)		
1: 1	Reps	Measure single thermocouple
2: 21	10 mV, 60 Hz Reject, Slow Range	Integration range
3: 1	DIFF Channel	Measure on Different channel #1on 23x panel
4: 1	Type T (Copper-Constantan)	Thermoucouple type in HDS
5: 1	Ref Temp (Deg. C) Loc [panel]	Location of reference temperature
6: 3	Loc [temp2]	Output location for final temperature
7: 1.0	Mult	Slope of calibration curve (1.0 is default)
8: 0.0	Offset	Offset of calibration curve (0.0 is default)
Z=X-Y (P35)		
1: 3	X Loc [temp2]	Final temperature after 20 seconds of heating
2: 2	Y Loc [temp1]	Initial temperature before heating
3: 4	Z Loc [deltaT]	Change in temperature
End (P95)		End delay; leave loop
Do (P86)		
1: 51	Set Port 1 Low	Turn off CE8 interface; stop current excitation HDS

3.2 Need for Desiccant

Desiccant material is normally stored inside the environmental enclosure which houses the data logger and the unshielded leads from the HDS and other sensors. The desiccant (CSI, model DSC20/4) reduces the humidity level so that corrosion is minimized. Each logger box has a color indicator for humidity. The desiccant will no longer absorb water from air when humidity level is too high. However, material can be serviced by placing it in a drying oven so that the water evaporates.

4.0 References

Campbell Scientific, Inc. 1999. 229 Soil water potential probe. Technical Note. Campbell Scientific, Inc. Logan, UT.

Reese, C.F. 1996. Evaluation of a line heat dissipation sensor for measuring soil matric potential. Soil Sci. Soc. Am. J. 60:1022-1027.

Young, M.H., P.J. Wierenga, A.W. Warrick, L.L. Hofmann, S.A. Musil, M. Yao, C. Mai, B.R. Scanlon. 1999. Results of field studies at the Maricopa Environmental Monitoring Site, Arizona. NUREG/CR-5694, U.S. Nuclear Regulatory Commission, Washington, DC.

Young, M.H. 2000. Task 4 Report - Calibration Manual. Submitted under Contract No.: KE56201-0-GA0052, Vadose Zone Monitoring System Deployment (U). ERDA/SRS.

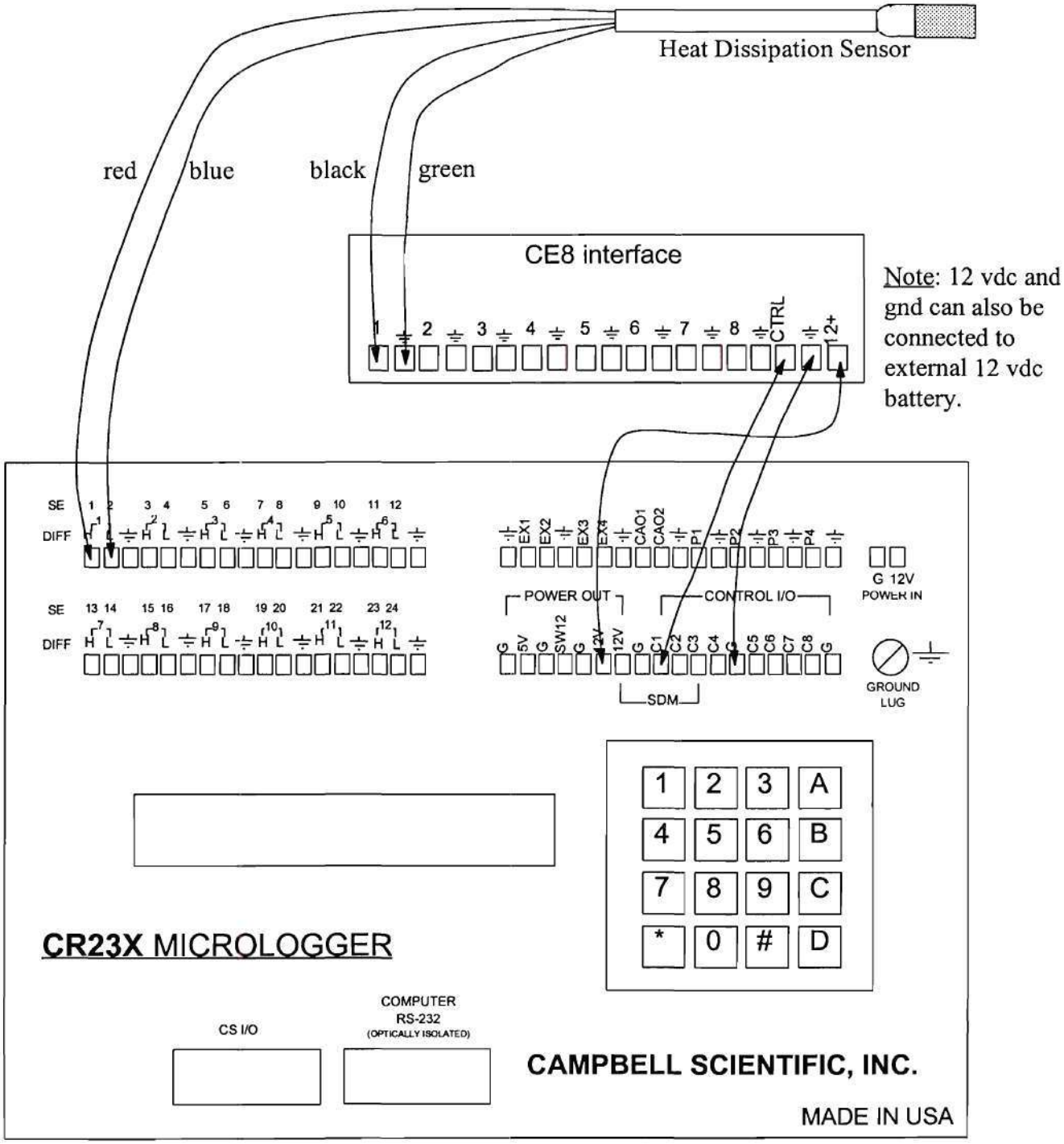

Figure 4-1 Schematic of Campbell Scientific CR-23X datalogger, CE8 constant current interface, and associated wiring requirements for the HDS.

Appendix 4 -

Operation and Maintenance of Porous Cup Lysimeters -

SOP 5.0, v 1.0

STANDARD OPERATING PROCEDURE 5.0

Operation & Maintenance of Porous Cup Lysimeters
v 1.0

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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1.0 Introduction and Scope of Procedure

The porous cup lysimeters are used to sample soil pore water for subsequent chemical analysis of radionuclides or other dissolved constituents. A total of four lysimeters were installed in each of three monitoring boreholes, as well as in four slanted boreholes adjacent to Slit Trench #1 at the E-Area disposal facility. Table 5-1 shows the locations. The lysimeters were purchased from Soil Moisture Equipment (model 1920F1L24-B1M3, Goleta, CA). The porous ceramic cup is 4.8 cm (1.9 inch) long and 5 cm (2 inches) in diameter, and epoxied to a PVC tubing that is 67 cm (22 inches) long. The sampler is placed under vacuum and water is removed through two polyethylene tubes that are connected to the top of the sampler. The tubes extend to ground surface. Figure 5-1 shows a schematic of the sampler.

This operation and maintenance section is abbreviated because a procedure for sampling the porous cup lysimeters is currently in place at the Savannah River Site (Proc. #SW 15.1-SOP-LYSI-01, Rev. 0, 8/31/99), obviating the need to rewrite the procedure herein. A copy of this procedure is attached as Appendix 1. However, some items regarding maintenance issues of lysimeters were not included in the SRS procedure, so these are included below.

2.0 Standard Operating Procedures

Refer to Appendix 1 (#SW 15.1-SOP-LYSI-01, Rev. 1, 10/12/99), with the following recommended changes as detailed below.

1. Pressurizing sampler - Steps 21-24, Page 5
   Procedures listed in these steps call for de-pressurizing the samplers for extended time periods, sometimes on the order of several days or longer, before collection of fluid.

Table 5-1 ID numbers and locations for porous cup lysimeters.

Borehole ID	Sensor ID	Depth	Location
		------ m (ft) -----	
5	5-SS-1-23	7.0 (23)	E of slit trench #1
5	5-SS-2-32	9.8 (32)	E of slit trench #1
5	5-SS-3-42	12.8 (42)	E of slit trench #1
5	5-SS-4-57	17.4 (57)	E of slit trench #1
6	6-SS-1-24	7.3 (24)	E of slit trench #1
6	6-SS-2-34	10.4 (34)	E of slit trench #1
6	6-SS-3-43	13.1 (43)	E of slit trench #1
6	6-SS-4-55	16.8 (55)	E of slit trench #1
7	7-SS-1-12	3.7 (12)	N of slit trench #1
7	7-SS-2-23	7.0 (23)	N of slit trench #1
7	7-SS-3-42	12.8 (42)	N of slit trench #1
7	7-SS-4-54	16.5 (54)	N of slit trench #1
	SL1	13.7 (45)	SE of slit trench #1
	SL2	13.7 (45)	SE of slit trench #1
	SL3	13.7 (45)	SE of slit trench #1
	SL4	13.7 (45)	E of slit trench #1

These actions are taken to ensure adequate volumes of water are collected for chemical analysis. Though no harm should come to the samplers by taking this approach, two unintended problems can result: 1) readings from other sensors in the monitoring boreholes appear to be affected for long-time periods, requiring more time for the sensors to re-equilibrate with the soil water conditions (Young, 2000), and 2) it is difficult to establish a date for the sampling because flow rate into the sampler can occur over many days.

It is recommended that vacuum be imposed on the solution samplers for the minimum time necessary to collect enough water for chemical analysis. It was also recommended by Wilson et al. (1995) that a constant vacuum, rather than a falling vacuum, be used whenever possible, because the chemistry of the sampled solution is more representative of fluid from both larger and smaller soil pores. Technical personnel should determine the volume of soil pore water needed and whether long term imposition of vacuum is needed. Assuming that a moderate volume of water is needed, it is recommended that the steps 21-24 be replaced as listed below:

21. REMOVE the black tubing from the pressure side of the pump.
22. CRIMP black tubing AND install plastic washer.
23. RETURN the lysimeter tubing pair back into the well casing.
24. RETURN to the well site approximately 24 hours prior to removal of fluid AND REMOVE the black tubing from the well casing.
25. UNBEND black tube by removing the plastic washer AND CONNECT black tubing *to the vacuum side of the pump.*
26. OPERATE pump until between minus 30 and 45 centibar (vacuum) is applied to the system.
27. CRIMP black tubing, AND INSTALL plastic washer.
28. REMOVE black tubing from the vacuum side of the pump, AND RETURN the tube pair back into the well casing.

3.0 Recommended Maintenance Activities

Biological or mineralogical build up on the porous ceramic material could eventually lead to reduced conductance of the sampler. The build up leads to decreased flow rates, and hence the need to further de-pressurize the sampler or to increase the sampling time in order to collect the same volume of fluid. Moreover, certain materials that build up on the ceramic could lead to

transformation of the dissolved constituents as they migrate through the ceramic (e.g., Lewis et al., 1992). It should be possible to remove some of these deposits on the ceramic using techniques normally used to prepare the sampler before installation. For example, Lewis et al. (1992) discuss the use of sodium hypochlorite as a biocide or copper salts that act as a bacteriostat, and that treatment of the samplers lead to greatly reduced effects on dissolved organic constituents. Hughes and Reynolds (1990) showed that flushing ceramic samplers with dilute HCl (pH = 3-4) released metals which had deposited onto the ceramic cup during the 6 years the samplers were in use. A heavy build up of a biofilm or metals on the ceramic could be reduced with *in-situ* treatment of the lysimeter.

Lysimeters installed in the monitoring boreholes are not removable, but some allowances for lysimeter replacement were designed into the slanted boreholes (SL1 - SL4). If the ceramic material is suspected of being clogged by a biological layer or mineralogical build up, the sampler can then be flushed in-place with either sodium hypochlorite or copper salts, or with dilute hydrochloric acid, according to the steps suggested below. It is stressed that these actions should be taken as a last measure, after it has been determined that the sampler performance has steadily worsened, and that insufficient sample volumes are collected. The technical personnel should consult the existing technical literature for updated research findings, prior to field treatment.

Materials:

1. Hand pump
2. Glass beaker
3. Deionized/distilled water (4 liters)
4. Log book
5. Treatment solution (either sodium hypochlorite, copper salts, or dilute hydrochloric acid)

Methods:

1. Prepare treatment solution.
2. Uncrimp the black tubing of the solution sampler and connect to the vacuum side of the hand pump
3. Uncrimp the green tubing and place inside the beaker of solution.
4. De-pressurize the sampler and check to be sure that at least 200 ml of solution is pulled into the green tubing and downward toward the sampler.
5. Remove the green tubing from the solution beaker and allow air to enter the tubing, thus draining the line.
6. Remove black tubing from the vacuum side of the hand pump, and crimp it so that it seals.
7. Place the green tubing on the pressure side of the hand pump and pressurize the sampler to less than one bar. The solution should be moving through the pores of the ceramic cup, removing the build up.
8. Remove the green tubing from the hand pump when the pressure begins to stabilize, indicating that fluid is no longer present in the cup.
9. Repeating steps 2 through 8, thoroughly clean the sampler, using deionized/distilled water instead of treatment solution. At least 3 full rinses should be done to ensure that the lines and sampler are clean.
10. When completed with the treatment, follow the procedures outlined in Procedure #SW 15.1-SOP-LYSI-01 to collect a soil water sample. The first sample collected after treatment should be discarded, as it may be affected by the treatment procedure.

4.0 References

Hughes, S., B. Reynolds. 1990. Evaluation of porous ceramic cups for monitoring soil-water aluminium in acid soils: comment on a paper by Fauland-Rasmussen (1989). J. Soil Sci. 41:325-328.

Lewis, D.L., A.P. Simons, W.B. Moore., D.K. Gattie. 1992. Treating soil solution samplers to prevent microbial removal of analytes. Applied and Environmental Microbiology. 58(1):1-5.

Wilson, L.G., D.W. Dorrance, W.R. Bond, L.G. Everett, S.J. Cullen. 1995. In-situ pore-liquid sampling in the vadose zone - Chapter 26. *In* Handbook of vadose zone characterization and monitoring. L.G. Wilson, L.G. Everett, S.J. Cullen, eds. CRC Press, Boca Raton, FL.

Young, M.H. 2000. Task 5 Report - Evaluation of Data from the Vadose Zone Monitoring System: E-Area Disposal Facility. Submitted under Contract No.: KE56201-0-GA0052, ERDA/SRS.

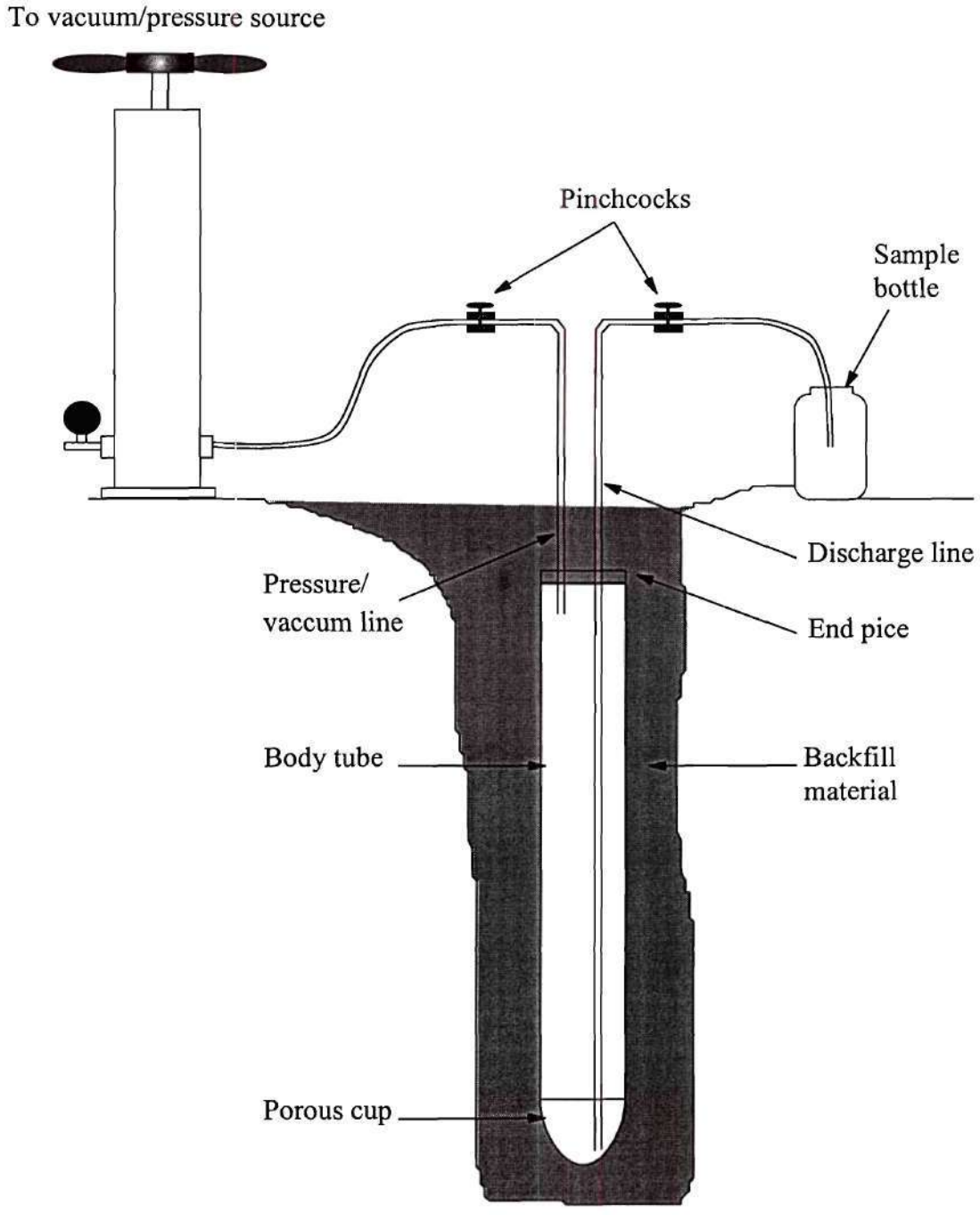

Figure 5-1 Schematic of single-chamber, pressure/vaccum porous cup lysimeter.

APPENDIX 1 -

Procedure #SW 15.1-SOP-LYSI-01, Rev. 1

IPC: _____ _____ _____ _____ _____

SW15.1 SWMF FACILITY OPERATING PROCEDURE

SAMPLING SWMF LYSIMETERS (U)

IPC# 724-99108 incorporated in this revision.

Prepared By: **David J. Wolfe, SWT&P**

Approved By: **M. F. Conrad, SWO**

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Purpose

To provide instructions for sampling Solid Waste Management Facility Lysimeters.

1.2 Scope

This procedure provides instructions for sampling porous cup lysimeters installed beneath trenches in the E Area Facility.

2.0 PRECAUTIONS AND LIMITATIONS

All protective equipment identified by RCO in the (S)RWP will be worn when performing this procedure. At a minimum, this will include safety glasses, rubber gloves, and TLD. RCO shall be present during sampling.

3.0 PREREQUISITE ACTIONS

None

4.0 PERFORMANCE SECTION

4.1 Lysimeter Sampling

NOTE:	The Shift Manager shall be notified immediately if a spill should occur during performance of this procedure.

1. **ENSURE** the following have been obtained. • Hand Pump, 16 Laboratory Tracking ID Labels and a copy of last analyical results • Pliers • Five gallon container • Black permanent marker • 16 sample bottles	• *SWE Vadose Zone Program Manager will provide these items.*
2. **ENSURE** gauge on pump is zeroed.	
3. **NOTIFY** Generator Certification Official (GCO) that job-controlled waste will be generated during performance of this procedure.	

4.1 Lysimeter Sampling, cont.

4. **NOTIFY** RCO that monitoring during the lysimeter sampling is required.	
5. **DON** all protective equipment identified by RCO.	
6. **ENSURE** RCO is present, **AND** **OPEN** well cap or stainless steel equipment cover.	6. *Pliers may be required to open well caps.*

NOTE: A lysimeter tube pair will consist of a black tube and a green tube; each marked with the same depth.

7. **REMOVE** lysimeter tube pair marked with the same depth from well casing.	7. *Black tube is for applying vacuum and pressure. The sample drains from the green tube.*
8. **MARK** a sample bottle with the lysimeter number and the depth identified on the lysimeter tube pair.	8. *Marking should be with a black permanent marker*
9. **APPLY** a bar code Laboratory Tracking ID Label to the sample bottle.	
10. **APPLY** a bar code Laboratory Tracking ID Label to Attachment 2, **AND** **COMPLETE** the following on Attachment 2.	
a. ID Number	a. *ID Number will be the lysimeter number and depth.*
b. Collection Date	
11. **ATTACH** end of black tube to the vacuum side of the hand pump.	
12. **UNBEND** black tube by removing the plastic washer, **AND** **RECORD** the vacuum from hand pump gauge on Attachment 1.	
13. **REMOVE** black tubing from the vacuum side of the pump, **AND** **ATTACH** black tubing to the pressure side of the pump.	

4.1 Lysimeter Sampling, cont.

14. **PLACE** collection bottle in the five-gallon container.
15. **UNBEND** the green tubing by removing the plastic washer, **AND**

    SECURE tubing to collection bottle.
16. **APPLY** pressure to the lysimeter system by **SLOWLY** pumping the hand pump until no more sample can be obtained.

    16. Collect as much sample as possible from each lysimeter
17. **SLOWLY** remove tubing from collection bottle while wiping tubing, **THEN**

    CAP collection bottle.

    17. Job-controlled waste will be handled per the S-7 Manual.
18. **REQUEST** RCO to survey the tubing end that came in contact with the sample, **AND**

    IF contamination is found, **THEN**

    - **FOLLOW** RCO directions
    - **NOTIFY** supervision
19. **CRIMP** green tubing, **AND**

    INSTALL plastic washer.
20. **RECORD** on Attachment 1 in ml the estimated amount of sample collected.
21. **REMOVE** the black tubing from the pressure side of the pump, **AND**

    CONNECT tubing to the vacuum side of the pump.
22. **OPERATE** pump until between minus 30 and minus 45 centibar (vacuum) is applied to the system.
23. **CRIMP** black tubing, **AND**

    INSTALL plastic washer.

    23. Tubing must remain crimped while it is removed from the pump or the vacuum will be lost.
24. **REMOVE** the black tubing from the vacuum side of the pump.

4.1 Lysimeter Sampling, cont.

25. **RETURN** the lysimeter tube pair back into the well casing.
26. **INSPECT** 5-gallon container for any liquid.
27. **IF** liquid if found in 5-gallon container, **THEN**

    POUR liquid in to sample bottle, **AND**

    REQUEST RCO survey the container.
28. **REPEAT** Steps 6 through 27 for each lysimeter to be sampled.
29. **ENSURE** well cap is replaced or stainless steel equipment cover is closed.
30. **OBTAIN** radiological survey and RAD labeling of sample container(s).
31. **REQUEST** RCO to perform a survey on the 5-gallon container.
32. **NOTIFY** the GCO for direction on disposal of job controlled waste.
33. **COMPLETE** the following on top portion of Attachment 2.
    - Requester Name
    - Date Submitted
    - Date Results Desired
34. **IF** Sample volume from lysimeter(s) is less than 5 mls, **THEN**

    RECORD lysimeter number(s) and Depth on Attachment 2.
35. **CONTACT** Hazardous Material Transportation Representative (HMTR) for shipping requirements.

32. *Job-controlled waste will be handled per the S-7 Manual.*

4.1 Lysimeter Sampling, cont.

36. **SUBMIT** Attachment 1 and 2 to the SWE Vadose Zone Program Manager for the following:

    - **ENSURE** Attachment 1 and Attachment 2 are correct and complete
    - **ENTER** Activity Code on Attachment 2

37. **TRANSPORT** samples to the Environmental Monitoring Section (EMS) labs in A-Wing of 735-A.

38. **WHEN** Chain-Of-Custody form is complete, **THEN**

    OBTAIN a copy and submit to the SWE Vadose Zone Program Manager.

Section Complete

5.0 REFERENCES

1. Documents That May Be Required To Use This SOP.

Manual(s)	Title
SW-QI-1171	*Records Management*
S7 Manual	Waste Management

- Procedure Number(s)

  None

- Drawing, Sketch, or Figure Number

  None

2. Other Documents Used To Write This SOP.

Manual(s)	Title
5Q Manual	*Radiological Control*
19Q Manual	*Transportation Safety*
WSRC - 3Q1-3	*Requirements For Submission, Receipt, And Handling Of Non-Routine Samples For Radioactive, Chemical, And Physical Determinations*

Procedure Number(s)	*Title*
IWT-OP-127	*Sampling E-Area Disposal Facility Lysimeters (U)*

- Drawing, Sketch, or Figure Number

  None

3. Technical Safety Requirements (TSR) References

   None

4. Process Hazards Review (PHR) References

   None

5. Process Requirements (PR) References

   None

6. Other References

   Identification Number

   None

6.0 RECORDS

Attachment 1 is the record generated due to the performance of this procedure and shall be processed in accordance with SW-QI-1171, *Records Management (U)*.

7.0 APPENDICES

NONE

8.0 ATTACHMENTS

1. **Lysimeter Data Sheet**
2. **Sample Request and Chain-of–Custody Data Sheet**

ATTACHMENT 1 Page 1 of 1

Lysimeter Data Sheet

Lysimeter #	Lysimeter Depth	Initial Vacuum	Estimated Sample in ml	Final Vacuum
AL-1	45 Feet	Centibars	ml	Centibars
AL-2	45 Feet	Centibars	ml	Centibars
AL-3	45 Feet	Centibars	ml	Centibars
AL-4	45 Feet	Centibars	ml	Centibars
AT-5	23 Feet	Centibars	ml	Centibars
	33 Feet	Centibars	ml	Centibars
	42 Feet	Centibars	ml	Centibars
	57 Feet	Centibars	ml	Centibars
AT-6	24 Feet	Centibars	ml	Centibars
	34 Feet	Centibars	ml	Centibars
	43 Feet	Centibars	ml	Centibars
	55 Feet	Centibars	ml	Centibars
AT-7	12 Feet	Centibars	ml	Centibars
	23 Feet	Centibars	ml	Centibars
	42 Feet	Centibars	ml	Centibars
	54 Feet	Centibars	ml	Centibars

Completed By:

Signature | Print Name | Date | Time

Supervisor Reviewed By:

Signature | Print Name | Date | Time

ATTACHMENT 2

Page 1 of 1

Sample Request and Chain-of–Custody Data Sheet

EMS ANALYSIS REQUEST AND CHAIN-OF-CUSTODY (Routine Turnaround)

Requestor must complete fully

Requestor Name SWMF	Phone 952-3725	Activity Code	Date Submitted	Date Results Desired
Report Results To: (Name) H. Holmes Burns	Department SWE	Building # 724-9E	Phone/Beeper # 2-3725/ 16916	FAX # 2-4405

Has this type of sample ever been EMS? ■ analyzed at

If NO, complete the separate EMS Sample Description Checklist to identify potential hazardous components.

Data Quality Level (DQO) Required
- ☐ Screening (SRS Internal Use)
- ■ EMS Routine
- ☐ Definitive (EPA Reportable)

Electronic Data Deliverable (EDD) Required
- ☐ None Required
- ☐ Mail Message
- ☐ AN Format (GIMS Compatible)
- ■ Other: CC Mail

Sample Hazards For Handling ☐ Yes ■ No List _____

Sample Hazards For Disposal ☐ Yes ■ No List _____

Do any samples contain radioactivity above environmental backgroundlevels? ☐ Yes ☐ No If YES, provide alpha, beta/gamma, and tritium estimates below.

Laboratory Tracking ID (Assigned by EMS Lab)	Sample ID & (Provided by Requestor)	Activity Level of Sample to Analyzed * (Provided by or Another SRS	Gross α, β	Tritium	Total Activity	Total Sr	Gamm Spec	Isotopic Alpha Spec Am/Cm	Isotopic Alpha Spec Pu	Isotopic Alpha Spec U	Other
Place Sticker Here	ID / Collection Date	Gross α / Gross β, γ / Tritium	√	√	*		√				
Place Sticker Here	ID / Collection Date	Gross α / Gross β, γ / Tritium	√	√	*		√				
Place Sticker Here	ID / Collection Date	Gross α / Gross β, γ / Tritium	√	√	*		√				
Place Sticker Here	ID / Collection Date	Gross α / Gross β, γ / Tritium	√	√	*		√				

See Attached Analytical Results

Comments (include sampling purpose, sampling interval, total release volume, or total flow, as applicable)

Handle as radioactive, Request laboratory add preservative.

Sample Disposal
- ☐ Return to customer
- ■ EMS Lab to Dipose -- Each sample is NOT an EPA/SCDHEC Hazardous Waste or Customer has identified hazardous constituents by completing the EMS Sample Description Checklist

Relinquished By: (Print)	Date	Received By: (Print)
(Sign)	Time	(Sign)

*Liquid samples with concentrations exceeding the following limits will not be accepted by EMS until the Environmental and Chemistry manager (or designee) has authorized the sample submission. Tritium: 100,000 pCi/ml (0.1μ Ci/ml or 222,000 dpm/ml); Alpha: 10 pCi/ml (22 dpm/ml); Beta: 20 pCi/ml (44 dpm/ml); Gamma: 20 pCi/ml (44 dpm/ml).

* Consider Total Activity protocol if insufficient quantities for Tritium and Gross γ, β

Sample volume from lysimeter(s) less then 5 mls for alternate analytical protocols.

Lysimeter Number(s) _____ Depth _____

Appendix 5 -

Data Logger Program Listing for Loggers 6 and 7

The table found below contains the code listing for program SRS-NOT5.CSI. This program listing controls data loggers 6 and 7 at the E-Area Slit Trenches. The loggers are part of the Vadose Zone Monitoring Program. Annotations accompany the commands where appropriate

;{CR23X} ;SRS Vadose Zone Monitoring System 4/1999 ; ;Program by Buck Sisson, 4/19/99 ;THIS IS FOR WELL NOT #5 IE W/O BAROMETER	
* Table 1 Program 01: 3600 Execution Interval (seconds)	*60 minute time interval between readings*
1: Panel Temperature (P17) 1: 1 Loc [Panel_T]	*Obtain temperature at the logger panel*
2: Batt Voltage (P10) 1: 2 Loc [Batt_Volt]	*Obtain battery voltage*
; Read CS505s each one is activated on a separate control line ; this was done to prevent interference ; Note here: Cell phone is on CA1, CS505s start on CA2 ; CS505s are on SE chnls 1-4, pressure sensors on Diff Chnl 7-10	
3: Do (P86) 1: 42 Set Port 2 High	*Set control port #2 high, thereby allowing for readings to be taken with WCR probe #1*
4: Period Average (SE) (P27) 1: 1 Reps 2: 4 200 kHz Max Freq @ 500 mV Peak to Peak, Period Output 3: 1 SE Channel 4: 10 No. of Cycles 5: 5 Timeout (units = 0.01 seconds) 6: 3 Loc [Wc_1] 7: .001 Mult 8: 0.0 Offset	*Collect water content data from WC_1*
5: Do (P86) 1: 52 Set Port 2 Low	*Turn off control port #2, because water content readings have been taken*

6: Do (P86) 1: 43 Set Port 3 High	*Set control port #3 high, thereby allowing for readings to be taken with WCR probe #2*
7: Period Average (SE) (P27) 1: 1 Reps 2: 4 200 kHz Max Freq @ 500 mV Peak to Peak, Period Output 3: 2 SE Channel 4: 10 No. of Cycles 5: 5 Timeout (units = 0.01 seconds) 6: 4 Loc [Wc_2] 7: .001 Mult 8: 0.0 Offset	*Collect water content data from WC_2*
8: Do (P86) 1: 53 Set Port 3 Low	*Turn off control port #3, because water content readings have been taken*
9: Do (P86) 1: 44 Set Port 4 High	*Set control port #4 high, thereby allowing for readings to be taken with WCR probe #3*
10: Period Average (SE) (P27) 1: 1 Reps 2: 4 200 kHz Max Freq @ 500 mV Peak to Peak, Period Output 3: 3 SE Channel 4: 10 No. of Cycles 5: 5 Timeout (units = 0.01 seconds) 6: 5 Loc [Wc_3] 7: .001 Mult 8: 0.0 Offset	*Collect water content data from WC_3*
11: Do (P86) 1: 54 Set Port 4 Low	*Turn off control port #4, because water content readings have been taken*
12: Do (P86) 1: 45 Set Port 5 High	*Set control port #5 high, thereby allowing for readings to be taken with WCR probe #4*
13: Period Average (SE) (P27) 1: 1 Reps 2: 4 200 kHz Max Freq @ 500 mV Peak to Peak, Period Output 3: 4 SE Channel 4: 10 No. of Cycles 5: 5 Timeout (units = 0.01 seconds) 6: 6 Loc [Wc_4] 7: .001 Mult 8: 0 Offset	*Collect water content data from WC_4*
14: Do (P86) 1: 55 Set Port 5 Low	*Turn off control port #5, because water content readings have been taken*

;Now read the pressure sensors starting on Diff Chnl 7	
15: Full Bridge (P6) 1: 4 Reps 2: 22 50 mV, 60 Hz Reject, Slow Range 3: 7 DIFF Channel 4: 1 Excite all reps w/Exchan 1 5: 5000 mV Excitation 6: 7 Loc [PT_1] 7: 1.0 Mult 8: 0.0 Offset	*P6 instruction takes readings from four-wire, full bridge transducers. 4 reps indicate that 4 transducers, in sequential order on the logger, will be interrogated, i.e., channels 7-10.* *with data stored in locations 7-10 (PT_1 through PT_4). Raw data are stored.*
16: If time is (P92) 1: 0000 Minutes (Seconds --) into a 2: 60 Interval (same units as above) 3: 10 Set Output Flag High (Flag 0)	*If the data logger clock indicates top of an hour, then print out stored data:* *Output flag high ≡ print statement*
;Save data in Table 1	
17: Real Time (P77) 1: 1120 (Same as 1220) Y,D,Hr/Mn	*Begin print job by printing logger time*
18: Resolution (P78) 1: 1 High Resolution	*Print all data at high resolution - 4 bytes per reading, instead of 2*
19: Sample (P70) 1: 10 Reps 2: 1 Loc [Panel_T]	*P70 Sampling sends 10 data locations (e.g., 10 reps) to final output beginning with Panel_T, and continuing to the end of record*
;Turn on the phone at 10 am for 1 hr	
20: If time is (P92) 1: 600 Minutes (Seconds --) into a 2: 1440 Interval (same units as above) 3: 41 Set Port 1 High	*If the data logger clock indicates 10:00 am, then turn on cellular phone. Cell phone connected to digital control port #1*
;Turn off the phone at 11 am	
21: If time is (P92) 1: 660 Minutes (Seconds --) into a 2: 1440 Interval (same units as above) 3: 51 Set Port 1 Low	*If the data logger clock indicates 11:00 am, then turn off cellular phone, thereby restricting access to others.*
* Table 2 Program 02: 0000 Execution Interval (seconds)	
End Program	**End of program**

VADOSE ZONE MONITORING SYSTEM DEPLOYMENT (U)

Task 4 Report - Final

Calibration Manual

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

Prepared by:
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March 2000

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1. Introduction

A Vadose Zone Monitoring System (VZMS) was deployed in early 1999 to provide data and information about possible downward flux of water and contaminants emanating from the E-Area Disposal Facility trench area at the Savannah River Site (SRS), which could potentially contaminate ground water. The VZMS consists of monitoring sensors installed in clusters at four depths in each of three boreholes. The sensors measure subsurface conditions including soil water potential, soil water content and pore water concentration. Four other boreholes are equipped with devices that sample soil pore water only. Soil water content and water potential data have been collected continuously from installation through the present, and soil pore water samples were collected periodically.

The sensors used in the VZMS require different levels of calibration to ensure that the sensor response can be converted to a physical condition in the soil profile. The purpose of this calibration report is to present calibration procedures for each sensor that requires some type of conversion from an electrical response to a physical condition. In addition, a procedure is included that describes pressure testing of a soil pore water sampler. The report describes the step-by-step methodology used for previously-installed sensors, and for sensors to be installed in the future.

The scope of this report is limited to the specific sensors used in the VZMS, either currently installed, or to be installed to support future monitoring programs. Though some information on sensor characteristics are included, specifications will not be described per se; instead, references or manuals on the sensors, which can assist technical personnel to understand sensor operation, will be referenced when appropriate. Operations and maintenance procedures are contained in a separate report under this contract (Young, 2000). Field calibration procedures, which are used to maintain sensors, will be included therein.

This document will present each calibration procedure as a standalone document, which can be used exclusively for calibrating specific sensors. Each procedure is attached as an appendix. A total of 4 procedures is included: INEEL Advanced Tensiometers (SOP 2.0), Water Content Reflectometers (SOP 3.0), Heat Dissipation Sensors (SOP 4.0), and Porous Cup Lysimeters (SOP 5.0).

2. References

Young, M.H. 2000. Task 3 Report - Final - Operation and Maintenance Manual. Vadose Zone Monitoring System Deployment (U). Contract No.: KE56201-0-GA0052. ERDA/SRS.

Appendix 1 -

Calibration of INEEL Advanced Tensiometers -

SOP 2.0, v 1.0

STANDARD OPERATING PROCEDURE 2.0

Calibration of INEEL Advanced Tensiometer
v 1.0

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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1.0 Introduction and Scope of Procedure

The INEEL Advance Tensiometer (IAT) is used to measure soil water potential in 12 separate locations, all adjacent to Slit Trench #2 at the E-Area disposal facility. The IATs were fabricated and assembled by Buck Sisson and Joel Hubbell (Hubbell and Sisson, 1998) of the Idaho National Engineering and Environmental Lab (Idaho Falls, ID). The IATs consist of several components, some of which were permanently installed in the soil (e.g., the ceramic cup and outer pipe) and others of which are retrievable, including the gasket assembly, pressure transducer and associated wiring.

This section describes the calibration of pressure transducers and the pressure testing of the ceramic cup that represents the critical components of the IAT.

2.0 Laboratory testing of IAT components

2.1 Calibration of Pressure Transducers

Materials:

1. Data logger
2. Pressure transducers
3. Vacuum source
4. Vacuum gauge, either manometer or hand-held pressure sensor with readout
5. Manifold for testing multiple transducers at a single time (optional)
6. Log book
7. Stopcock

Methods:

The steps listed below describe calibration of electronic pressure transducers with ±15 psi (~1000 cm H_2O) span, such as those used in the VZMS.

1. Connect the pressure transducers to the data logger as described in the user's manual. Figure 2-1 shows the wiring of a single transducer to a Campbell Scientific, Inc. data logger, model CR-23X. The 23X logger is used in the VZMS.
2. Write down the PT number and data logger port used during calibration.
3. Connect the port side of the pressure transducer to the vacuum source, usually with flexible (Tygon®) tubing. If more than one pressure transducer is calibrated at a time, then it will be necessary to connect all transducers to the single vacuum source using a manifold, similar to that shown in Figure 2-2.
4. Connect the vacuum source to a manometer that has both water and mercury U-tubes, or to a hand-held pressure sensor with readout (e.g., Tensimeter®, Soil Measurement Systems, Tucson, AZ).
5. Collect at least 20 data points with the transducers open to atmospheric conditions.
6. Connect the vacuum source to the pressure transducers and zero out the vacuum.
7. Collect at least 20 data points. Alternatively, let the system stabilize and then collect a single reading.
8. Choose a series of pressure/vacuum steps (e.g., 500, 200, 100, 75, 50, 25, 10, 5, -5, -10, -25, -50, -75, -100, -200, -500 and maximum possible (in units of cm of H_2O)).
9. Between each pressure/vacuum step, close the stopcock to be sure that no leaks in the system will cause drift.
10. Begin the calibration by slowly increasing pressure on the transducer, until maximum pressure is obtained.
11. Change the pressure/vacuum level to the next step and collect data points. Be sure to write down the exact vacuum readings, in "H_2O" from pressure/vacuums of 0 to ±100 cm and in "Hg" for pressure/vacuums higher than ±100 cm water, if a manometer is used. This is done by checking the water level in both sides of a manometer U-tube. Write

down the pressure/vacuum level on the hand-held device, if this is used. It is more important to exactly measure the vacuum levels than it is to try and get the vacuum level to a specific value.

12. When all the vacuum steps have been used, download the data onto the PC using the communication software that accompanied the datalogger.
13. Read the data into either a spreadsheet program, or some other program capable of performing simple linear regression.
14. Manually type in the measured vacuum readings into the table using the values as the dependent variable.
15. Regress the voltage reading from the transducer onto the measured vacuum (i.e., choose the datalogger output as the independent variable and the measured vacuum as the dependent variable).
16. Check the coefficient of determination (r^2) to see that the calculated value exceeds a user-specified criteria (e.g., $r^2 > 0.999$).

2.2 Pressure Testing of Ceramic Cup

Materials:

1. Tensiometer
2. Vacuum pump
3. Log book or data sheet
4. Tygon® tubing
5. Y- or T-connector
6. Collection flask

Methods:

1. Soak the tensiometer in DI water for several hours.
2. Connect a piece of clear tubing to the tensiometer.

3. Connect the other side of the Tygon to a pressure/vacuum source.
4. Re-immerse the tensiometer in DI water and apply vacuum until water is seen in the Tygon (e.g., tensiometer is filled with water).
5. Remove water.
6. Apply pressure to the tensiometer beginning at 50 cm H_2O for and increase in 50 cm H_2O increments every until 1) leaks occur, 2) the bubbling pressure of the ceramic material is reached, or 3) pressure exceeds ~650 cm H_2O.
7. Record the bubbling pressure in the log book or data sheet. If pressure exceeds 650 cm H_2O, then record bubbling pressure as "BP > 650 cm H_2O."

3.0 Other Relevant Issues

None

4.0 References

Hubbell, J.M., J.B. Sisson. 1998. Advanced tensiometer for shallow or deep soil water potential. Soil Sci. 163(4):271-77.

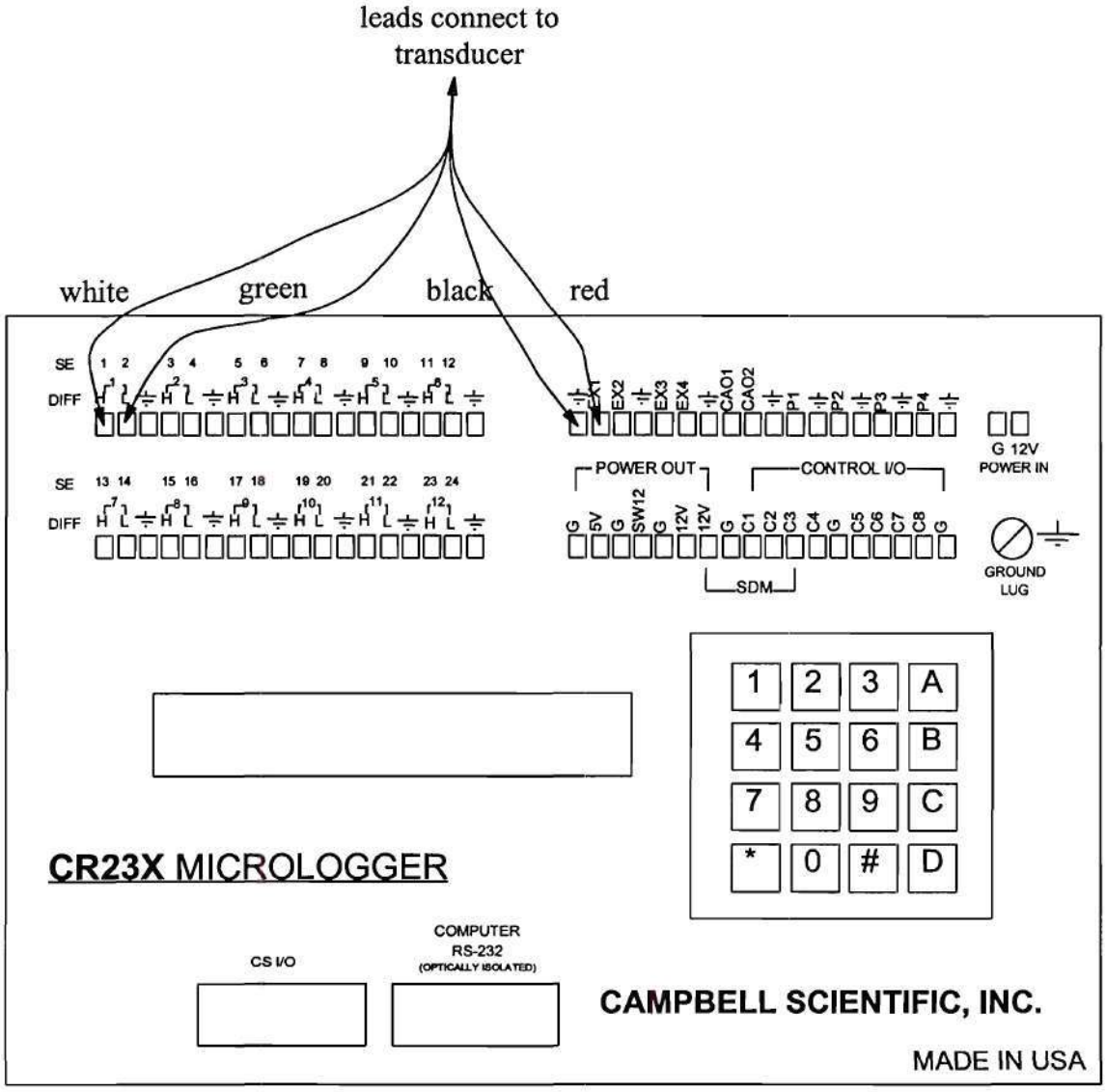

Figure 2-1 Schematic of Campbell Scientific CR-23X datalogger and transducer wiring.

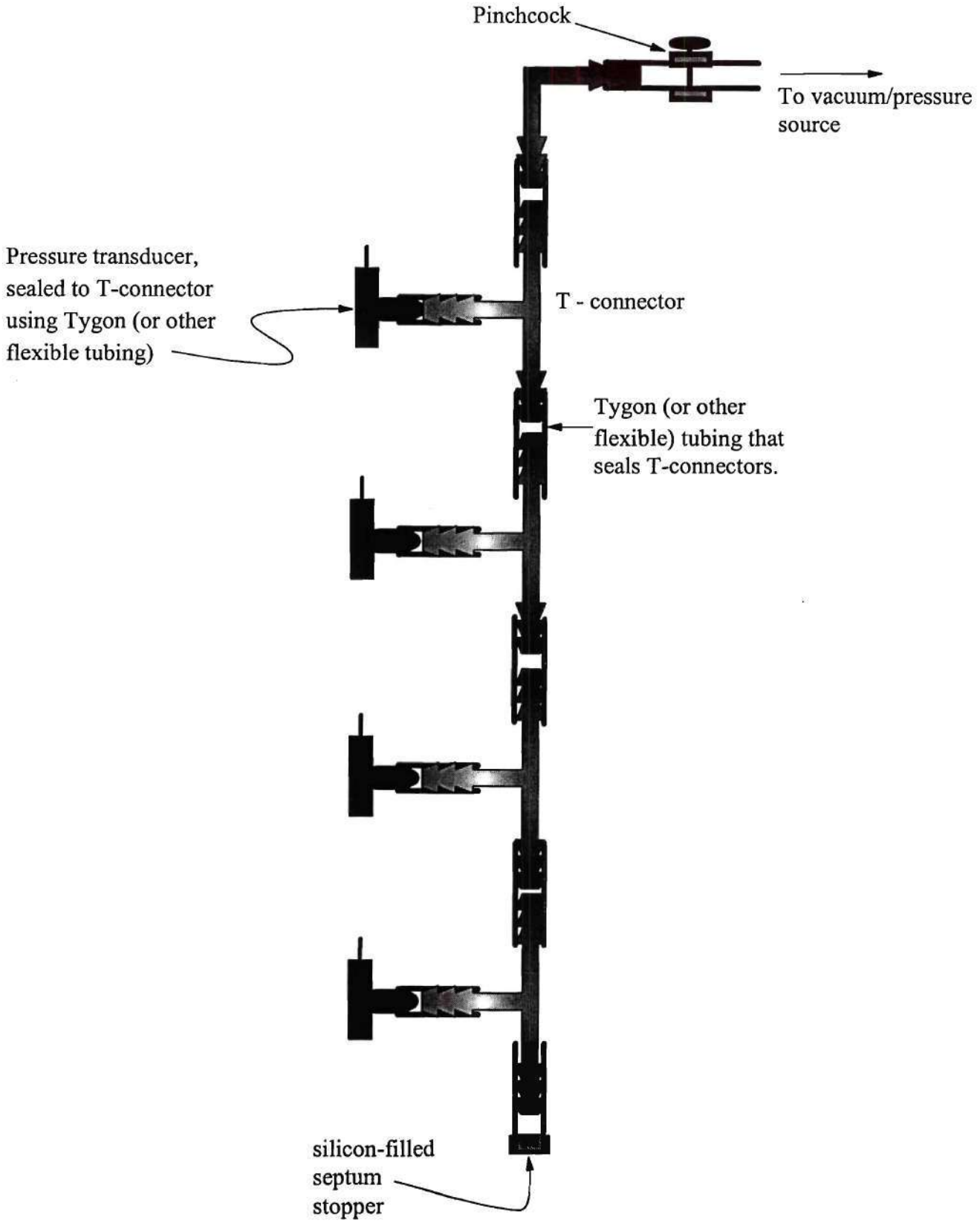

Figure 2-2 Schematic of vacuum manifold for multiple transducer calibration.

Appendix 2 -

Calibration of Water Content Reflectometers -

SOP 3.0, v 1.0

STANDARD OPERATING PROCEDURE 3.0

Calibration of Water Content Reflectometers
v 1.0

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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None listed

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1.0 Introduction and Scope of Procedure

The Water Content Reflectometer (WCR; model CS 505-L, Campbell Scientific, Inc., Logan, UT) is used to measure soil water content at the E-Area disposal facility. The WCR sensor, also marketed as a Fuel Moisture Sensor, measures the time necessary for an electromagnetic wave pulse to travel from the sensor handle to the sensor tip, and back again. Though a factory calibration curve exists that relates the pulse travel time to the water content, soil specific calibration curves will provide more accurate estimates of water content. The sensors are fully contained units, they need calibration to relate the pulse travel time. These sensors cannot be recalibrated in the field after installation.

Operation of the WCR involves simple wiring and data logger programming. These aspects of sensor operation were discussed in full by Young (2000); for the sake of efficiency, they will not be repeated herein. This section will describe the laboratory procedures for calibrating WCR sensors.

2.0 Standard Operating Procedures

The method presented below involves the step increase in water content from air dry to saturation. The soil and probe are packed into a chamber a single time, and water is then added to the chamber in specific steps. This method is thus insulated from the effects of changing soil bulk density as the water content is increased and the soil is repacked into the chamber. Because the water content reading is a volumetric average of soil and water that surround the entire probe, the reading is accurate even if water content gradients exist in the chamber when the reading is taken. The method below describes a step-by-step procedure for calibrating the WCR sensors.

Materials:

1. Acrylic soil chamber (dimensions: 15.2 cm diameter by 23 cm length)
2. Water content sensor (model CS 505-L, Campbell Scientific, Inc., Logan, UT)
3. Data logger (model CR-23X data logger, Campbell Scientific, Inc., Logan, UT)
4. Test soil (origin: Savannah River Site)
5. Test solution (deionized/distilled) mixed to 0.005 M $CaSO_4$
6. Balance
7. Graduated cylinder
8. Tamping device for packing soil

Methods:

1. Prepare WCR sensor using the method of Sisson (1999), specifically referring to the bonding of the sensor onto plastic foam and PVC sheet.
2. Prepare the test soil:

i. Oven dry the soil at 105 °C for 24 hours.

ii. Grind the dried soil so that it passes a 2-mm sieve.

iii. Store the soil in a water-tight (e.g., Ziploc) bag.

3. Measure the effective volume of the soil chamber (volume of soil chamber minus volume of sensor and foam attachment)
4. Place and secure the sensor into the soil chamber.
5. Measure the mass of the sensor (with wiring) and chamber, and record in log book or data sheet.
6. Add soil to the chamber in increments of approximately 2.54-cm and pack the soil using a tamper to the approximate field bulk density.
7. Continue adding soil to the chamber until the soil surface reaches the top of the brass wave guides of the sensor.
8. Measure the mass of the sensor (with wiring), chamber and soil, and record in log book or

data sheet.

9. Determine the dry bulk density (ρ_b) of the soil material in the chamber:

$$\rho_b = \frac{(Total\ mass\ of\ column - Mass\ of\ column\ setup\ without\ soil)}{Effective\ soil\ volume} \quad (3\text{-}1)$$

10. Calculate the soil porosity:

$$Porosity = 1 - \left(\frac{\rho_b}{2.65} \right) \quad (3\text{-}2)$$

11. Wire the WCR sensor to the data logger according to Figure 3-1. It is assumed that the period averaging method of sensor interrogation is used (see Young (2000) for wiring and interrogation using the pulse counting method). Figure 3-2 is a schematic of the setup.
12. Collect water content measurements until the readings stabilize.
13. Measure enough test solution to raise the soil water content by 5% volumetric water content (0.05 cm^3/cm^3), using:

$$Volume\ test\ solution = \frac{(0.05)(Mass\ of\ oven\text{-}dried\ soil)}{\rho_b} \quad (3\text{-}3)$$

14. Add the test solution to the top of the soil chamber, ensuring that ponding does not lead to loss of water from the chamber. Cover the soil surface with parafilm or some other material that prevents soil evaporation.
15. Allow the water to redistribute in the chamber for at least 24 hours.
16. Follow steps 12 through 15, until either water ponds on the soil surface indefinitely, or the volumetric water content equals or closely approaches the porosity (Equation 3-2).
17. When the calibration test ends, measure the mass of the soil chamber, sensor (with wires), and wetted soil. Calculate the mass of wetted soil.
18. Subtract the original weight measurement of the chamber setup with oven-dried soil from

the chamber setup with wetted soil. The difference should be very close to the total water added to the soil chamber.

19. Carefully remove all soil from the chamber, and place the entire amount in a soil drying oven for 24 hours at 105°C.

20. Calculate final volumetric water content:

$$\textit{Final vol. water content} = \left(\frac{\textit{Mass of wetted soil} - \textit{Mass of oven-dried soil}}{\textit{Mass of oven-dried soil}} \right) \times \rho_b \quad (3\text{-}4)$$

21. Back calculate the volumetric water content for each calibration step by subtracting the volume of test solution added to the soil chamber in sequential steps. This is done by correcting for the "Mass of wetted soil" shown in Equation (3-4) and recalculating the volumetric water content. These water content values will be used during the linear regression for obtaining the calibration parameters.

22. Read the data from the logger into either a spreadsheet program, or some other program capable of performing simple linear regression.

23. Manually type in the measured volumetric water content values into the spreadsheet using the values as the dependent variable.

24. Regress the pulse period reading from the logger onto the measured water content (i.e., choose the datalogger output as the independent variable and the measured water content as the dependent variable).

25. Check the coefficient of determination (r^2) to see that the calculated value exceeds a user-specified criteria (e.g., $r^2 > 0.99$).

26. Calibration parameters should be established for that sensor.

27. Repeat the above steps for a sufficient number of sensors to quantify variability between sensors.

3.0 Other Relevant Issues

None

4.0 References

Sisson, J.B. 1999. Evaluation of sensors used in the vadose zone monitoring system. Report submitted to SRS/SWM. August, 1999.

Young, M.H. 2000. Task 3 Report - Final - Operations and Maintenance Manual. Submitted under "Vadose Zone Monitoring System Deployment (U)," Contract No.: KE56201-0-GA0052. ERDA/SRS.

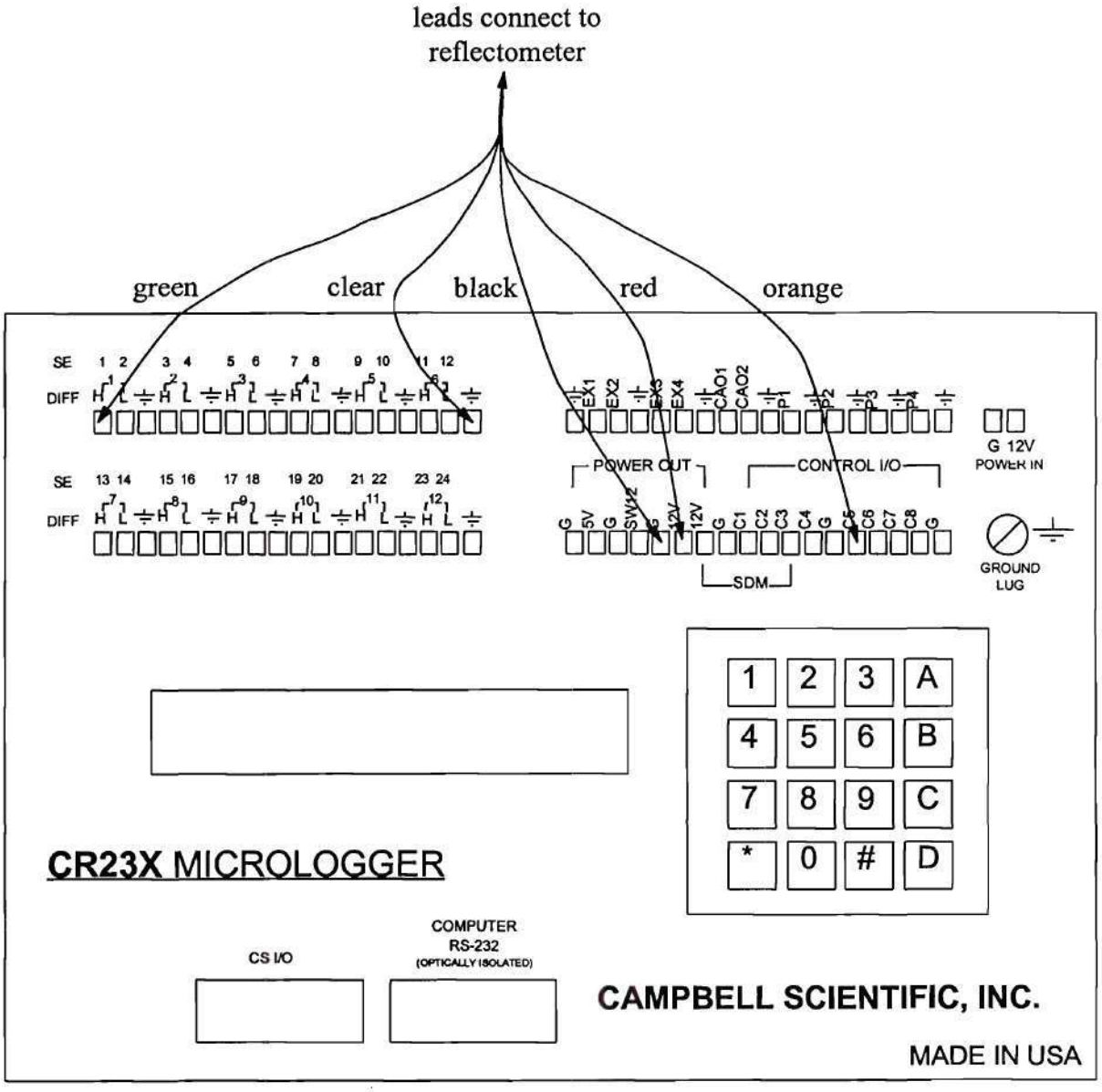

Figure 3-1 Schematic of Campbell Scientific CR-23X datalogger, with associated wiring requirements for period averaging.

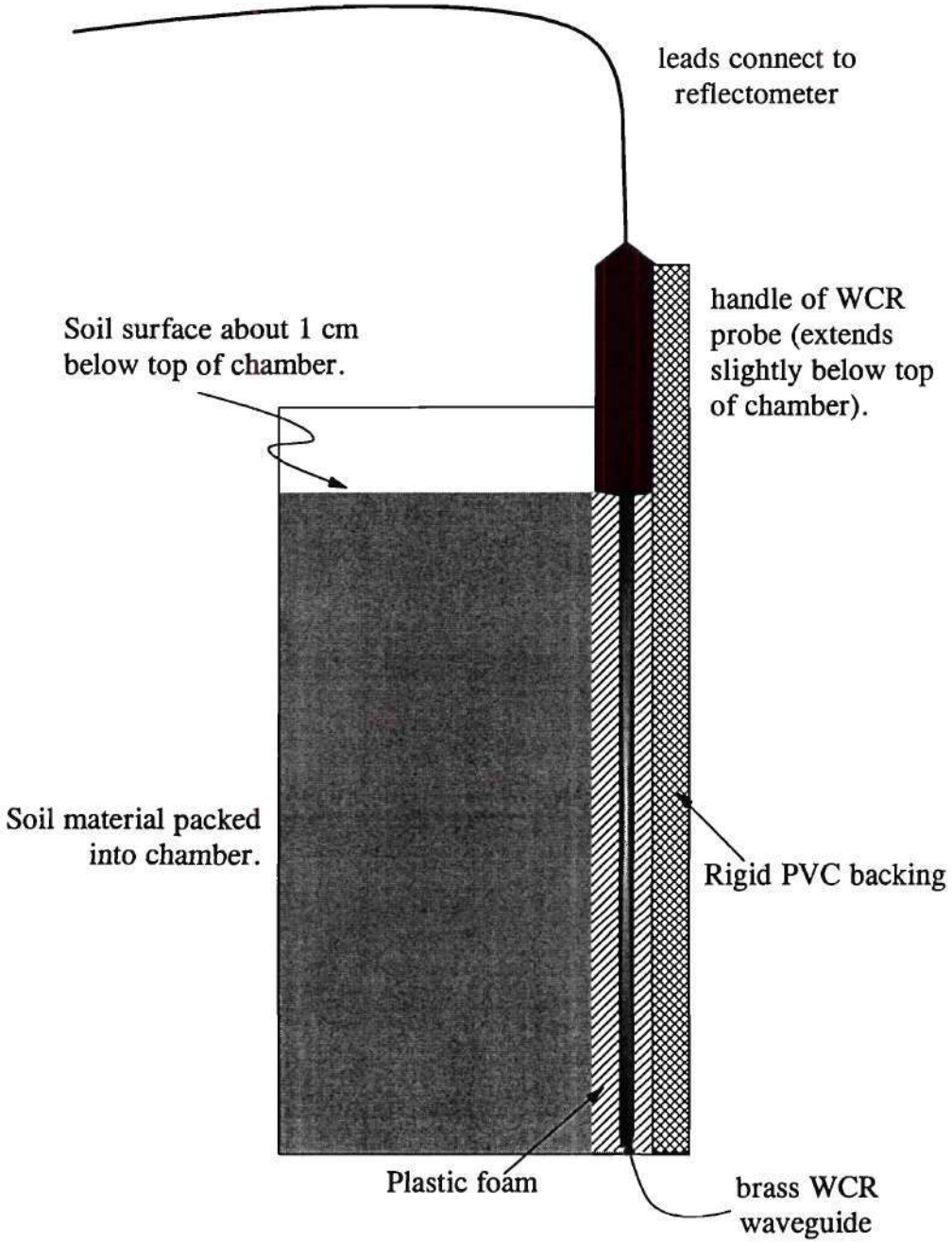

Figure 3-2 Laboratory setup showing the soil chamber and sensor.

Appendix 3 -

Calibration of Heat Dissipation Sensors -

SOP 4.0, v 1.0

STANDARD OPERATING PROCEDURE 4.0

Calibration of Heat Dissipation Sensors
v 1.0

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

Prepared by:

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The Heat Dissipation Sensors (HDS, model 229, Campbell Scientific, Inc., Logan, UT) are planned for use in the Mega-Trench site; no HDS are used at the Slit Trenches at the E-Area disposal facility. The HDS sensors, also referred to as Soil Water Potential Probes, are fabricated at CSI and are fully contained units. The HDS does not require any active maintenance, though protection of the electrical leads from corrosion should be done. These sensors cannot be recalibrated in the field after installation.

1.1 Brief Background on Heat Dissipation Sensors

The HDS consists of a heating element and temperature thermocouple, both surrounded by a rod-shaped, porous ceramic material. The heating element is connected to a constant current interface which provides 50 milliamps ± 0.25 milliamp of current. The current causes heat to build up along the heating element. The change in heat is then recorded using the thermocouple. Movement of thermal energy away from the heating element and toward the thermocouple depends on the thermal conductivity of the ceramic, and the thermal conductivity, in turn, depends on the water content of the ceramic. Higher water content causes higher thermal conductivity. The magnitude of the temperature increase recorded by the thermocouple will be less in wetter material because conduction causes greater dissipation of heat.

Because the ceramic is porous and in contact with the soil, water will flow toward or away from the ceramic, depending on the potential energy differences between the soil and ceramic. If the ceramic material is drier than the soil, it will absorb water until the potential differences are negligible, and vice versa.

The Campbell data logger controls the constant current interface (model CE-8) using one of the digital control ports. When the control port is set high, the constant current interface energizes the heating element. The data logger is then instructed to measure the thermocouple temperature

after two time delays, usually after one second, and then again after usually 20-25 sec. The difference in recorded temperatures is known as the ΔT. After measuring the ΔT, the current excitation at the heating element ceases. Calibration research on the HDS (Reese, 1996) has confirmed that the natural log of the soil water potential is linearly related to ΔT, using:

$$\ln(|\psi|) = \alpha \Delta T + \beta \quad (4\text{-}1)$$

where ψ is the soil water potential, α is the calibration slope, and β is the offest. The operational range of the HDS is influenced, in part, by the resolution of the data logger to measure very small changes in temperature. Data loggers with higher analog/digital conversion rates are able to detect smaller changes in temperature. The upper limit of the operational range, therefore, is limited by the soil wetness, usually corresponding to a soil water potential of -100 cm of H_2O (CSI, 1999), though Young et al. (1999) was able to calibrate the sensor to a soil water potential of -50 cm H_2O). Very dry soils with potentials less than several hundred bar are still measurable with the HDS (Levitt, Bechtel Nevada, personal communication, 2000).

2.0 Calibration Procedures

Two different calibration apparatuses can be used to expedite calibration by increasing the number of sensors that could be processed at one time and to minimize equilibration time. The procedures are listed separately depending on the range of soil water potential targeted.

2.1 Calibration in Wetting Soils

Materials:

1. 25 x 25 x 10 cm water-tight plastic containers (e.g., Tupperware® containers)
2. Test soil
3. #7 Cork borer

4. Tensiometer
5. Hand-held pressure sensor, or pressure transducers to equip the tensiometers

Methods:

1. Wire HDS according to the diagram in Figure 4-1
2. Prepare an adequate amount of site soil by air drying and passing the soil through a sieve with 2-mm openings. Enough soil should be prepared to fill three plastic containers.
3. Pre-wet three batches of soil to different soil water potentials. This is done by adding different amounts of water to bring up the soil water content to levels that correspond to soil water potentials of approximately -50, -100, -200 cm H_2O, and allowing the soil to equilibrate in ziploc bags for at least 24 hours. Water content of the packed soil can be checked using the method of Gardner (1986).
4. Pack each of the three "calibration tubs" with the site soil to approximately field bulk density.
5. Use a #7 cork borer to cut guide holes in the soil slightly smaller in diameter then the HDS ceramic plug, maximizing ceramic plug/soil contact. Begin the calibration procedure with the wettest soil first.
6. Insert the sensors into the holes so that the porous ceramic is a minimum of 2 cm below soil surface in the tubs. Calibration procedures used by Young et al. (1999) called for six HDS installed at one time, so several can be calibrated simultaneously. Figure 4-2 shows the sequence of calibration tubs.
7. Route the HDS wire leads through holes cut into the container lid, and wire them either 1) directly to a CE8 constant current interface (model CE8, Campbell Scientific, Inc. Logan, UT) and the data logger, or 2) to a multiplexer relay (model AM416, Campbell Scientific, Inc. Logan, UT), a CE8 constant current interface (model CE8, Campbell Scientific, Inc. Logan, UT), and the data logger.
8. Plug the lid holes with rubber stoppers and secure the stopper with duct tape to minimize water loss from evaporation.

9. Insert two tensiometers (e.g., model SW-014, Soil Measurement Systems, Tucson, AZ) into the soil at the same depth as the HDS plug. The tensiometers are used to independently measure soil water potential.
10. Measure the soil water potential from the tensiometer using a hand-held pressure transducer (e.g., Tensimeter®, Soil Measurement Systems, Tucson, AZ), or equip the tensiometers with pressure transducers. Measurements of soil water potential should follow the method of Cresswell (1993).
11. Average the potential measurements, and use as the independent variable for generating the calibration curves.
12. Sample the HDS every four hours until they equilibrate with the soil. A criteria used by Young et al. (1999) was to consider the sensors at equilibrium when no changes in ΔT occurred for 24 hours (6 readings).
13. After equilibration, carefully remove the sensors from the calibration tub and reinsert them into the tub with the next drier soil. For example, if the sensors were installed in Calibration tub #1 (e.g., potential = -50 cm H_2O), then they would be moved to Calibration tub #2 (potential = -100 cm H_2O).
14. Continue monitoring using steps 4 - 11. If more HDS are needed for calibration, they can be added to the recently-used tub, using the same guide holes as the first batch.
15. Continue moving the sensors to the next drier calibration tub until all sensors have been tested in each of the three tubs, and they have all reached equilibration at the different soil water potentials.

2.2 Calibration in Drier Soils

Calibration potentials of less than -1000 cm H_2O cannot be verified using standard tensiometry because these dry conditions exceed the bubbling pressure of the tensiometer cup, and hence it's workable range. An alternative is to use the pressure plate apparatus similar to that described by Fredlund and Wong (1989) to obtain these calibration points. The method described below should be used as a starting point for the technical personnel. It is urged that the personnel refer

to the Methods of Soil Analysis (Klute, 1986) for further specific information on laboratory equipment that is needed for calibrating HDS under dry conditions.

Materials:

1. Pressure extractor similar to model 1000 (Soil Moisture Equipment Corp., Goleta, CA)
2. Silica flour
3. $CaSO_4$ solution
4. acrylic retaining rings

Methods:

1. Position the sensors in a 7.35-cm diameter by 3.5-cm tall acrylic retaining ring sitting on a 15-bar ceramic plate (model 0675B15M1, Soil Moisture Equipment Corp., Goleta, CA). One pressure plate apparatus should have a 6 sensor capacity. Figure 4-3 is a schematic of the HDS and retaining ring.
2. Prepare a slurry consisting of 0.005 M $CaSO_4$ solution and 325 mesh silica flour.
3. Pour the slurry into the retaining ring completely encasing the sensor.
4. Route the HDS wire leads through a 6 mm (¼-inch) compression fitting sealed with nylon ferrules to prevent cutting the leads.
5. Wire all sensors into the data logger and constant current interface outside of the pressure pot, following the wiring diagram in Figure 4-1.
6. Seal the pressure pot, and set the pressure value to 1000 cm H_2O (~1 bar).
7. Using a data logger program similar to that listed in Table 4-1, collect ΔT values until they remain unchanged for 24 hours and ceramic plate outflow had ceased.
8. If needed, change the pressure level to a higher value, and begin collecting data as above.

3.0 Other Relevant Issues

3.1 Calibration curve

Data collected from both the HDS while in the calibration tubs and the pressure pot should be integrated into a single calibration curve. The curve should be of the form as Equation 4-1, where the ΔT data are used as the independent variables in the calibration curve, and the Tensimeter and pressure gauge measurements are used as the dependent variables. Perform a least squares regression on the data using any of many available spreadsheet or analytical packages.

3.2 Data Logger Instructions for HDS Interrogation

Campbell Scientific, Inc. uses P-instructions for interrogating HDS sensors. The set of instructions specifies the location of the excitation and digital control ports, resolution of the analog (voltage)/digital conversion, output location for the reading, and calibration parameters (if chosen). Using the PC208W software to program the data logger, the sets of P-instructions that interrogate the HDS are described below.

The set of instructions for interrogating the HDS is listed in Table 4-1. Explanations accompany each instruction. Note that temperature measurements are made three times: 1) ambient temperature used as a reference, 2) initial temperature at the HDS sensor, 3) final temperature after 20 seconds of current heating. The second and third temperature measurements are used for determining ΔT, and the P35 instruction calculates the ΔT value. Instructions for initiating and stopping the current heating surround the final measurement. Note that the integration range, parameter #2 in the temperature measurement can be increased if the temperature is too high for accurate conversion to digital value. The final ΔT value is then used in a calibration curve, as shown in Equation 4-1.

Table 4-1 Campbell Scientific, Inc. instructions for HDS interrogation.

Panel Temperature (P17)		
1: 1	Loc [panel]	Obtain reference temperature
Thermocouple Temp (DIFF) (P14)		
1: 1	Reps	Measure single thermocouple
2: 21	10 mV, 60 Hz Reject, Slow Range	Integration range
3: 1	DIFF Channel	Measure on Different channel #1on 23x panel
4: 1	Type T (Copper-Constantan)	Thermoucouple type in HDS
5: 1	Ref Temp (Deg. C) Loc [panel]	Location of reference temperature
6: 2	Loc [temp1]	Output location for initial temperature
7: 1.0	Mult	Slope of calibration curve (1.0 is default)
8: 0.0	Offset	Offset of calibration curve (0.0 is default)
3: Do (P86)		
1: 41	Set Port 1 High	Turn on CE8 interface, begin current excitation
Beginning of Loop (P87)		
1: 1	Delay	Delay the program for 2 x 1 second to stabilize
2: 1	Loop Count	HDS sensor
End (P95)		End delay
Beginning of Loop (P87)		
1: 1	Delay	Delay the program for 20 x 1 second to allow
2: 20	Loop Count	temperature dissipation to occur.
Thermocouple Temp (DIFF) (P14)		
1: 1	Reps	Measure single thermocouple
2: 21	10 mV, 60 Hz Reject, Slow Range	Integration range
3: 1	DIFF Channel	Measure on Different channel #1on 23x panel
4: 1	Type T (Copper-Constantan)	Thermoucouple type in HDS
5: 1	Ref Temp (Deg. C) Loc [panel]	Location of reference temperature
6: 3	Loc [temp2]	Output location for final temperature
7: 1.0	Mult	Slope of calibration curve (1.0 is default)
8: 0.0	Offset	Offset of calibration curve (0.0 is default)
Z=X-Y (P35)		
1: 3	X Loc [temp2]	Final temperature after 20 seconds of heating
2: 2	Y Loc [temp1]	Initial temperature before heating
3: 4	Z Loc [deltaT]	Change in temperature
End (P95)		End delay; leave loop
Do (P86)		
1: 51	Set Port 1 Low	Turn off CE8 interface; stop current excitation HDS

stopping the current heating surround the final measurement. Note that the integration range, parameter #2 in the temperature measurement can be increased if the temperature is too high for accurate conversion to digital value. The final ΔT value is then used in a calibration curve, as shown in Equation 4-1.

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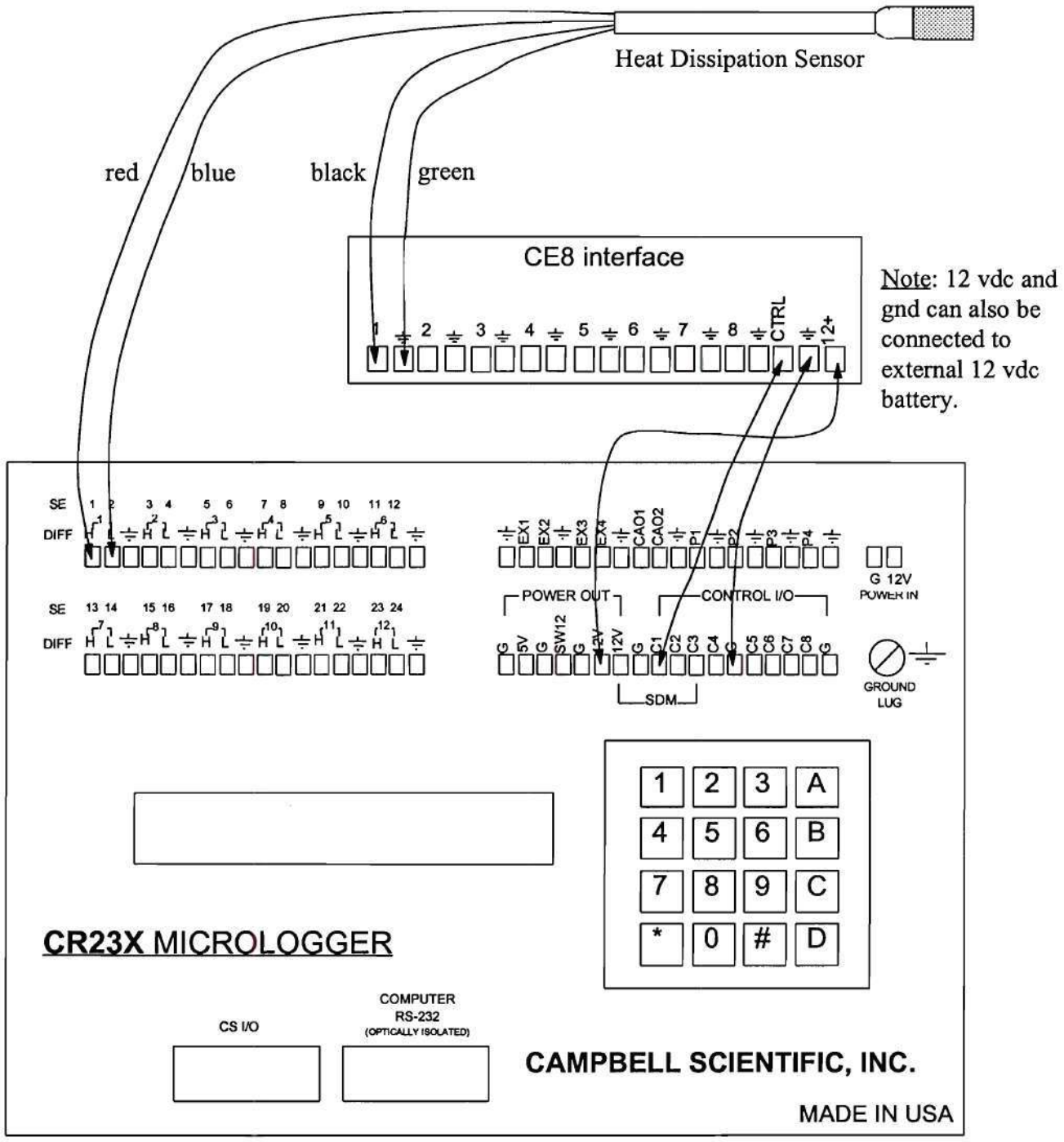

Figure 4-1 Schematic of Campbell Scientific CR-23X datalogger, CE8 constant current interface, and associated wiring requirements for the HDS.

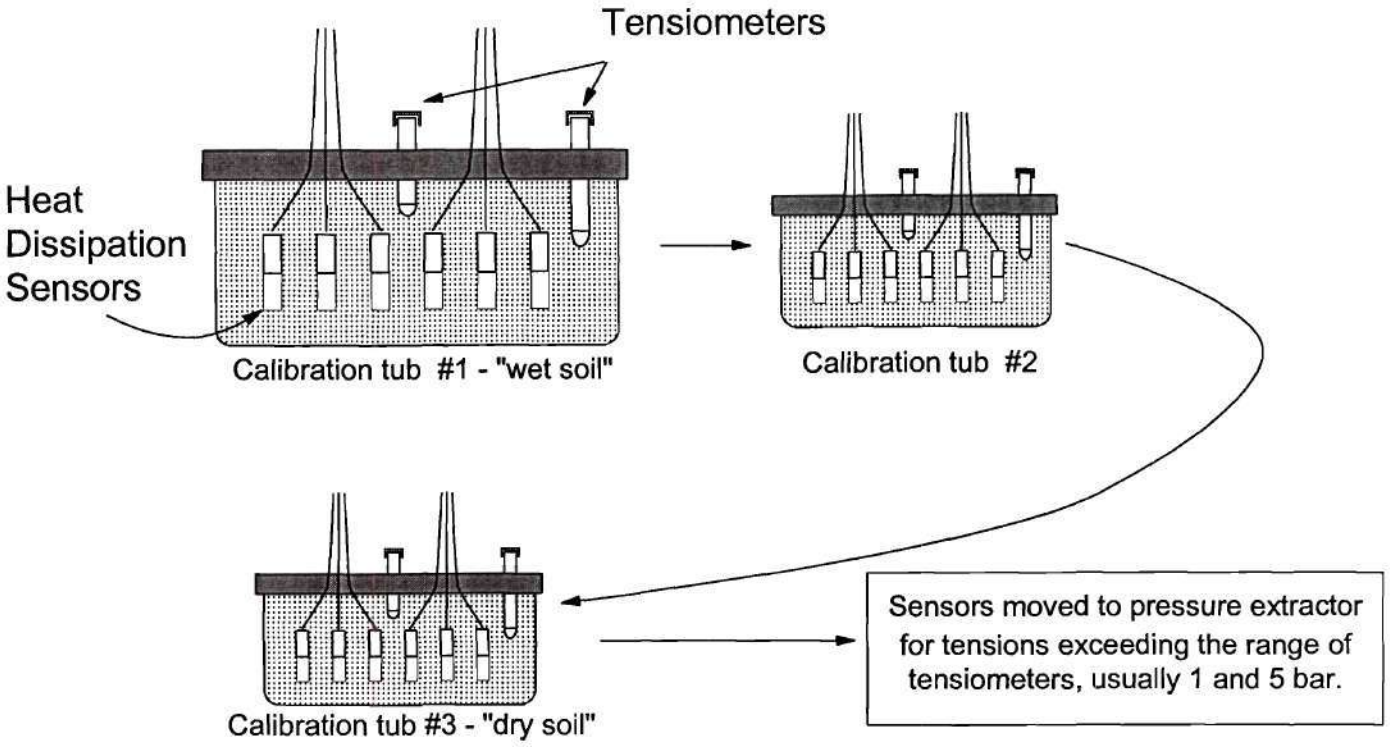

Figure 4-2 Schematic of HDS calibration using calibration tubs.

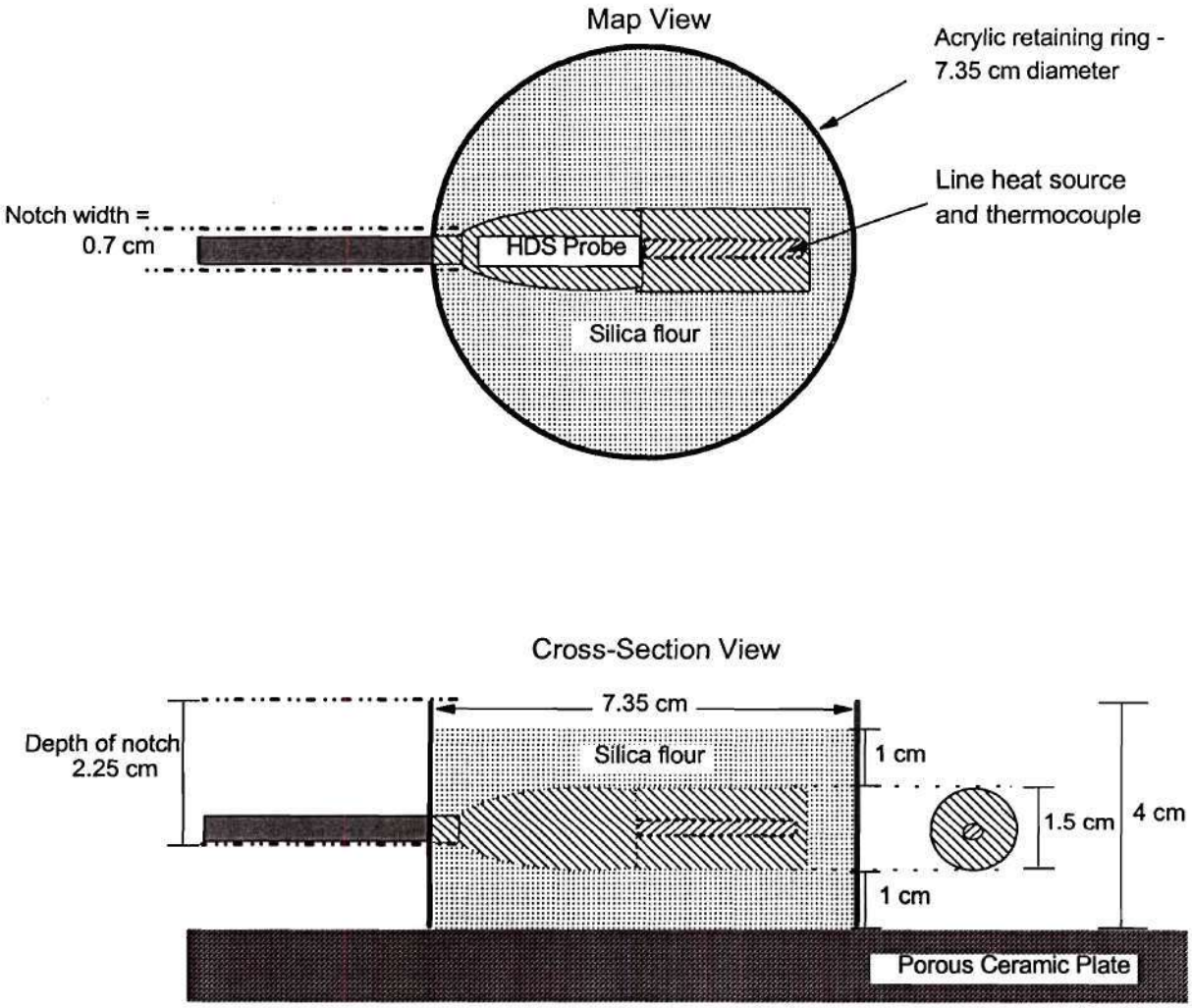

Figure 4-3 Schematic of HDS sensor and acrylic retaining ring used during the calibration with pressure extractor.

Appendix 4 -

Testing of Porous Cup Lysimeters -

SOP 5.0, v 1.0

STANDARD OPERATING PROCEDURE 5.0

Testing of Porous Cup Lysimeters
v 1.0

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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Revision 1: Developed by: _____ Date: _____
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Revision 2: Developed by: _____ Date: _____
Reviewed by: _____ Date: _____
Approved by: _____ Date: _____

Revision 3: Developed by: _____ Date: _____
Reviewed by: _____ Date: _____
Approved by: _____ Date: _____

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1.0 Introduction and Scope of Procedure

The porous cup lysimeters are used to sample soil pore water for subsequent chemical analysis of radionuclides or other dissolved constituents. A total of four lysimeters were installed in each of three monitoring boreholes, as well as in four slanted boreholes adjacent to Slit Trench #1 at the E-Area disposal facility. The lysimeters were purchased from Soil Moisture Equipment (model 1920F1L24-B1M3, Goleta, CA). The porous ceramic cup is 4.8 cm (1.9 inch) long and 5 cm (2 inches) in diameter, and epoxied to a PVC tubing that is 67 cm (22 inches) long. The sampler is placed under vacuum and water is removed through two polyethylene tubes that are connected to the top of the sampler. The tubes extend to ground surface.

This section describes the method for testing the ceramic material for abnormally large pores, which could cause the sampler to prematurely loose vacuum. Large pores that allow air to pass through the ceramic could render the sampler inoperable after installation. Therefore, each sampler needs to be pressure tested to ensure that the bubbling pressure will be suitable for sampling soil pore water in the field.

2.0 Standard Operating Procedures

Porous cup lysimeters should be tested in the field, immediately prior to installation. This ensures that instrument handling during fabrication and assembly does not cause leaks to occur.

Materials:

1. Porous cup lysimeters
2. Vacuum pump
3. Log book or data sheet
4. Tygon® tubing

5. Y- or T-connector
6. Large beaker or acrylic cylinder

Methods:

1. Take all materials to the field site where samplers are to be installed.
2. Soak the samplers in DI water for several hours.
3. Connect two pieces of 3.2 mm ID polyethylene tubing, which have been cut to the length used in the final installation.
4. Seal discharge line with pinchcock (Figure 5-1).
5. Connect the other end of the polyethylene tubing to a pressure/vacuum source .
6. Immerse the sampler vertically in deionized water so that the compression fittings are also below the water surface.
7. Apply vacuum to fill up the ceramic portion of the sampler with water.
8. Apply 15 psi (~1000 cm H_2O) pressure to the sampler, beginning at 50 cm H_2O, and increase in 50 cm H_2O increments until leaks occur or the bubbling pressure of the ceramic tube is reached. Bubbling pressure should be at least 650 cm H_2O.
9. Record the bubbling pressure in the log book or data sheet.

3.0 Other Relevant Issues

3.1 Repairing ceramic material

In some cases, manufacturing of the ceramic sampler may lead to a small number of pores that are much larger than the majority of pores in the tube. This is seen by the presence of air bubbles at lower pressures, before bubbling appear through most of the pores. These can be repaired using epoxy, as described below.

1. During normal pressure testings, look for small bubbles to appear in isolated areas in the ceramic material.

2. Remove the sampler from the water bath, and circle the area using either a permanent marker (e.g., Sharpie) or pencil.
3. Continue testing as described above until total bubbling occurs.
4. Place a small amount of two-part epoxy (e.g., Master Mend Extra working time, model TM-61, Loctite Corp., Rocky Hill, CT) directly onto the circled area. Work the epoxy into the ceramic material.
5. Allow the epoxy to dry according to manufacturers specification.
6. Follow the original pressure testing procedure described in Section 2.0.
7. If the epoxied area continues to leak, return the ceramic material to the manufacturer.

3.2 Replacing compression fittings

The majority of failures associated with the bubbling pressure tests likely will be caused by the compression fittings that connect the tubing to the sampler. The compression fittings are threaded into the sampler top, into which the polyethylene tubing is inserted and secured with a ring and ferrule. During the pressure testing, look specifically for air leaks at the junction of the fitting and sampler body, or at the junction of the fitting and the tubing. If leaks are seen at the fitting/sampler connection, then remove the sampler from the bucket, unscrew the fitting and check to see if the fitting is cross-threaded or otherwise faulty. It may be necessary to remove the teflon tape and retape the male thread. If leaks are seen at the fitting/polyethylene tubing connection, then remove the outer ring, and replace the ferrule that crimps down on the tubing. The outer ring on the sampler should be not overly tightened as it will damage the polyethylene tubing and promote leaks. Resoak the sampler and retest.

4.0 References

None.

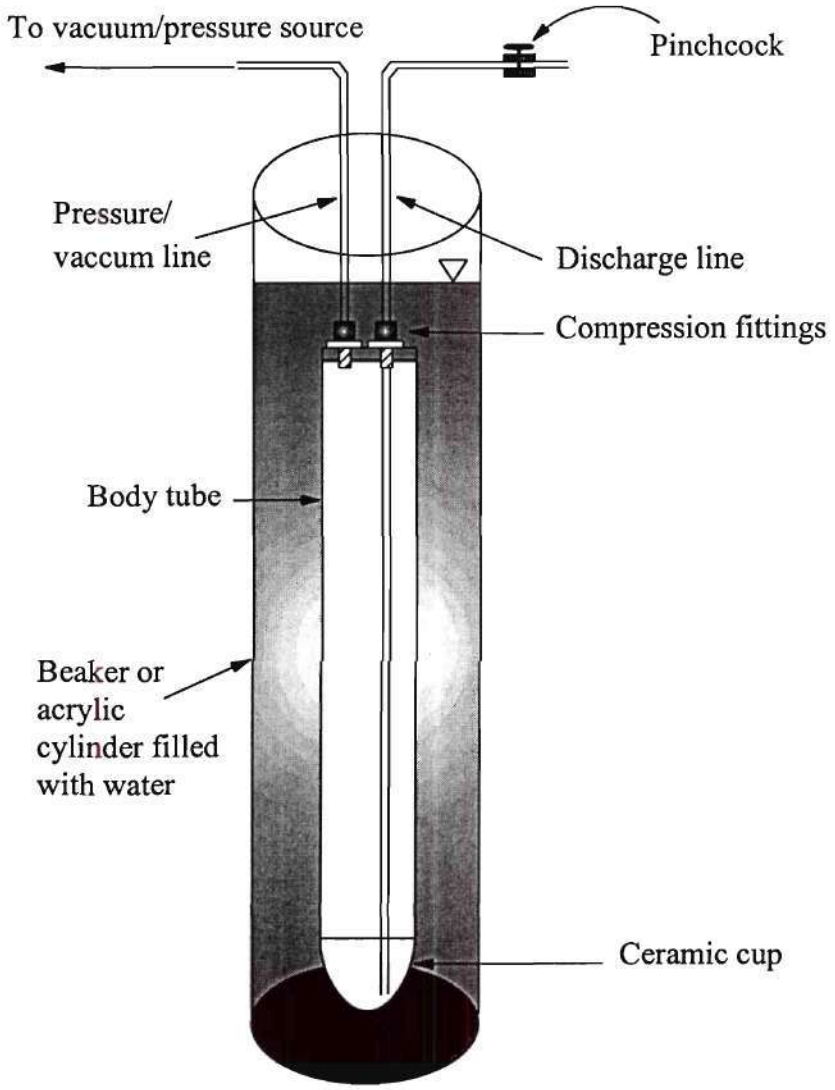

Figure 5-1 Schematic showing the setup for pressure testing porous cup lysimeters.

E-20-F39
#4

VADOSE ZONE MONITORING SYSTEM DEPLOYMENT(U)

Task 5 Report - Final

Evaluation of Data from the Vadose Zone Monitoring System: E-Area Disposal Facility

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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1. Introduction

A Vadose Zone Monitoring System (VZMS) was deployed in early 1999 to provide data and information about possible downward flux of water and contaminants emanating from the E-Area Disposal Facility trench area at the Savannah River Site (SRS), which could potentially contaminate ground water. The VZMS consists of monitoring sensors installed in clusters at four depths in each of three boreholes. The sensors measure subsurface conditions including soil water potential, soil water content and pore water concentration. Four other boreholes are equipped with devices that sample soil pore water only. Soil water content and water potential data have been collected continuously from installation through the present, and soil pore water samples were collected periodically.

This document is a follow-up from a deliverable submitted to the Educational Research and Development Agency (ERDA) which presented calculations of potential water flux through the soil material at the slit trenches at the E-Area disposal facility (Young, 1999). The document subsequently was forwarded to Ms. Heather Holmes-Burns (DOE/BNFL), the Task Order Representative for that contract (GA 0047). The purposes of this letter report are to 1) evaluate the behavior of the monitoring sensors used to support the existing VZMS, and 2) calculate estimates of water flux using VZMS data and hydraulic property data obtained from soil samples collected at the site and analyzed in the laboratory. This report describes the approach for the flux analysis.

Evaluation of monitoring data will focus primarily on data collected during a four-month period from September 1 - December 31, 1999. Data collected during earlier time periods will be discussed as appropriate; however, given that the hydrologic system and sensors were equilibrating, the data were not necessarily representative of long-term field conditions. Data collected during the last four months of 1999 appear to more closely represent the field conditions.

2. Data Analysis

The current VMZS consists of 3 data loggers, numbered 5 through 7, each operating four tensiometers (ATs), four water content reflectometers (WCRs), and four pore water samplers. Logger 5 also operates a tipping-bucket raingauge, calibrated so that one tip represents 0.25 mm (0.01 inch) of rainfall. Temperature and battery voltage data from each logger are stored for informational purposes. Data are stored hourly for all sensors. This portion of the report will describe the results from each logger individually.

A. Logger 5

Figure 2.1[1] shows precipitation recorded using the tipping-bucket raingauge. Hourly and cumulative amounts are shown. During the four-month time period described in this report, a total of just below 46.3 mm (1.82 inch) of precipitation occurred, with the bulk of that amount recorded on 23 September (7.62 mm) and 29-30 September (14.48 mm). With the close proximity of the other loggers to Logger 5 and to the slit trenches, these amounts are representative of rainfall that occurred at the slit trench site.

Figure 2.2A shows battery voltage levels oscillating between approximately 12.5 and 13.5 volts. Increasing the resolution of the graph shows daily highs during the afternoon and daily lows during the early mornings (graph not shown). Given that the battery voltage was greater than 11 volts, the power system for Logger 5 is more than sufficient to source current needs for the pressure transducers mounted on the ATs and for the WCR units.

Figure 2.2 B presents soil water content showing data from four depths. The lines are marked accordingly, though similarities between the different depths tend to obscure individual responses near the end of the time series. Water contents from at 16.8 m (55 ft) depth show gradual changes, with the highest values recorded on DOY 277 (4 Oct 99), followed by a steady

[1] All figures and tables are found at back of report

reduction. Though ground water levels are not available, the smooth increase and decrease in water content is most likely to water level fluctuations. Very slight water level declines were recorded from the other three probes, but the values themselves were highly repeatable. Several exceptions can be identified on DOY 256 (13 Sep 99), 313 (9 Nov 99), and 334 (30 Nov 99). Each of these days correlate with sampling events from the solution samplers, which took place two days earlier. The data show that hydraulic communication exists between the WCR and the solution samplers

Figure 2.2 C shows soil water potential for Logger 5. The data are marked by steady readings, interrupted by sampling events from the solution samplers that clearly alter the soil water potential readings for several days. Data collected from 16.8-m (55 ft) depth indicate the presence of the water table, capillary fringe, or some other feature that caused near saturation of water at the tensiometer cup. The subsurface condition should be confirmed using nearby monitoring wells, or possibly neutron probe data. Lack of saturated soil could indicate a possible leak in the tensiometer cup, with the pressure transducer providing offset readings only. The minor fluctuations, which are generally hidden due to resolution of the graph appear to show periodic behavior with a period length of 12 hours, amplitude of 2 cm, and with maximums occurring at 10:00 am and 10:00 pm. These values are consistent with the semi-diurnal behavior of earth tide loading from atmospheric heating and cooling (Miller and Thompson, 1979). The observed amplitude of 2 cm should not create uncertainties in the ability of the tensiometer to detect significant changes in soil water potential.

The shallow sensors did not detect any changes in water content or water potential caused by precipitation events during this monitoring period, as the upper soil layers replenished the soil water deficit that had developed during the summer months. The deficit increases the buffering capacity of the soil, reducing deeper responses caused by precipitation events. For example, if we assume that all 45 mm of precipitation occurred instantaneously (e.g., no evapotranspiration between events), an increase of 10% volumetric water content would be distributed with the upper 0.45 m of soil, much too shallow to be detected with the monitoring sensors installed at 6.7-m depth. Though water will redistribute vertically downward with time, an instantaneous

pulse of water input would be dissipated prior to reaching 6.7-m depth. Based on the available data, it appears that the current configuration of sensors will monitor deep soil water conditions only. If data on shallower conditions are needed to support an additional goal of the VZMS, then additional sensors would be needed.

Using data obtained from Shelby tube samples and analyzed for water retention characteristics, the paired values of water content and water potential can be fitted to a closed-form equation that describes the complete water retention curve, as shown by Equation (1) (van Genuchten, 1980):

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{(1+(\alpha\psi)^n)^m} \quad (1)$$

where θ_s is the saturated water content, θ_r is the residual water content, ψ is the soil water potential (L), and α, n, m are fitting parameters. Note that m is taken as m = 1-1/n. Figures 2.3A and B show the water retention curves for soil collected in Shelby tubes from 6.4-m and 12.5-m depths, respectively, adjacent to Logger 5. Data in Table 2.1 list the van Genuchten parameters. Included with each graph is a single data point taken from DOY 270, (27 Sep 99, 00:00 am). In both cases, the data point plots above the fitted retention curve, indicating an overestimation in either the water potential or water content, depending on which value is considered to be the "true" value (e.g., data with no bias or other error). If, for example the soil water potential is considered to be true value, then the water content could be overestimated by as much as 30% (equivalent to a water content of 0.07 cm^3/cm^3). If the water content is true, then the soil water potential would be about 1/3 of that measured with the tensiometer. Differences between the paired values of water potential and water content, from those obtained from the laboratory retention data, could be caused by several factors, including 1) spatial variability of soil properties between the sensors and the location of the Shelby tube samples, 2) disturbance of the soil sample during collection, or 3) a combination of the two, to name just a few.

Overall, data collected from the VZMS at Logger 5 appears to be in equilibrium with the soil, and appears to follow patterns expected of near-steady state conditions. Data loss due to instrument failure at this site has not occurred, but some of the soil water potential measurements

were affected by the long-term depressurization of the solution samplers. Shorter sampling events would prevent some of the loss of usable data from the tensiometers.

B. Logger 6

Figure 2.4 A shows the battery voltage for Logger 6. Power was maintained within the 12 - 13.5 volt range for virtually the entire monitoring period. The small dips in voltage below 12 volt occurred during a single collection event and the voltage returned thereafter. The power system appears to be operational and sufficient to power the logger and subsurface sensors.

Figure 2.4 B shows the soil water content from depths as listed on the figure. Similar to the sensor response from Logger 5, the readings were found to be highly repeatable. The general pattern of highest water content values at the bottom of the borehole, lowest values at 12.5 m depth, and intermediate values from the shallower sensors was identical to those found from Logger 5. However, it was noted that the overall readings, with the exception of the sensor at 16.8 m (55 ft) depth, were generally lower in magnitude than those collected from Logger 5, several meters away. Without textural data from each specific borehole, it is not possible conclude whether differences in water content are texturally controlled between the two boreholes, or whether the sensor data are systematically biased.

Very little variability between readings were recorded for any single WCR sensor, with the exception of the sensor installed at 12.5-m (41 ft) depth. Beginning on DOY 291 (18 Oct 99, 16:00), the sensor reading dropped from 0.192 to 0.145, and maintained the lower water content level throughout the remainder of the monitoring period. The raw data from the WCR revealed a decrease in the electromagnetic travel time down the probe, so the sensor response did, if fact, shift. No other sensors experienced a similar change in reading, and voltage levels were stable at the time. To the knowledge of the author, no other site activities occurred on that day. Therefore, either the sensor partially lost contact with the borehole wall or the sensor calibration suddenly shifted. It may be possible to check whether the former explanation has occurred by placing the solution lysimeter under high vacuum and observing the response of the WCR

sensor. Given that most of the sensors monitored by Logger 5 responded to the water sampling events, this could provide a means of checking the sensor contact: no response could indicate lack of contact and good response could indicate a change in calibration.

Figure 2.4 C shows the soil water potential for the ATs monitored using Logger 6. The tensiometers show slightly higher variability within each time series, than those recorded in Logger 5, but the differences in soil water potential between the tensiometers was very low. In fact, differences in potentials eventually fell to within approximately 25 cm at the end of the monitoring period. Some of the readings with obviously higher variability occurred at DOY 288 (15 Oct 99), 294 (21 Oct 99), and 304 (31 Oct 99), with the magnitude of the variability decreasing with increasing depth. Events similar to these were recorded by the Logger 5 tensiometers, though the magnitude was lower. The source of the variability appears to be earth tide loading, and not an indication of real changes in soil water potential. The overall magnitude of potential values were consistent with those recorded from Logger 5, with the exception of the tensiometers at 16.8-m (55 ft) depth; differences in potential indicate that the water table or capillary fringe is not present at 16.8 m depth at Logger 6. It would be important to confirm this finding using either monitoring well or neutron probe data, which could be used to detect the location of saturated to near-saturated material.

C. Logger 7

Voltage levels in Logger 7 (Figure 2.5 A) are consistent with those from the other loggers and are sufficient to power the attached sensors. Additional discussion is not needed.

Water contents are shown in Figure 2.5 B. Three of four sensors are shown because of a previously-known failure of the WCR at 3.4-m (11 ft) depth. Repeatability of measurements were observed, similar to those of other WCR sensors at other boreholes. Magnitudes of water content for the sensors at 6.7-m (22 ft) and 12.5-m (41 ft) depths appear to be similar to other sensors installed at those depths, with the understanding that variability of soil material will affect the water retention. The sensor installed at 16.2 m (53 ft), however, appears to be

recording low values. Readings of 20.8% volumetric water content at the beginning of the monitoring period were followed by a steady decline in water content to values of close to 17.5%. Though a 3% decline in the volumetric water content is not surprising in itself, these values are significantly lower than sensors installed in other boreholes at this depth. Lack of site specific textural data from Borehole 7 makes it difficult to understand the low values, so it would be justified to suggest evaluating the behavior of this sensor again in the future.

Briefly, soil water potentials shown in Figure 2.5 C follow the same basic pattern as seen in other boreholes. The tensiometers reacted to the imposition of vacuum on the solution samplers. The semi-diurnal fluctuations are manifested by high frequency variations in the potential readings, and do not indicate any significant changes soil conditions. The lack of change in magnitude of soil water potential shows that the subsurface system is near steady-state.

3. Estimates of Flux

A. Brief Background and Analytical Development

Fluid flux values, potentially containing radionuclides, are used as input to computer models by SRS personnel during their Performance Assessment (PA) modeling activities to evaluate whether the mass of tritium released from the site will exceed the Maximum Concentration Limit (MCL) of 20,000 pCi/L at a hypothetical receptor well located 100 m downgradient from the site.

This section provides an estimate of fluid flux using data obtained from the VZMS, and mass flux using tritium concentration data obtained from the solution samplers. The approach taken herein is similar to that used by Young (1999), where the parameters from the retention curve are used in the Mualem form of the hydraulic conductivity equation (Mualem, 1976):

$$K(\psi)=K_{sat}\frac{\left(1-(\alpha\psi)^{n-1}[1+(\alpha\psi)^{n}]^{-m}\right)^{2}}{[1+(\alpha\psi)^{n}]^{m/2}} \qquad (2)$$

where K_{sat} is the saturated hydraulic conductivity, measured in the laboratory, and α, m and n are fitting parameters determined from fitting retention data to Equation (1). The hydraulic gradient was calculated using soil water potential data collected with VZMS sensors in each of the three boreholes using $\Delta\psi/\Delta z = (\psi_1-\psi_2)/(z_1-z_2)$, where 1 and 2 are depth indices, increasing with depth. The fluid flux is determined using:

$$q = -K(\psi)\frac{dH}{dz} = -K(\psi)\frac{d}{dz}[\psi + z] \quad (3)$$

where q is flux (L/T), and H is total head consisting of soil water potential ψ and gravitational z components (L). Depth increases downward so that a positive quantity in q means flux in the downward direction.

The hydraulic conductivity equation was written as a function of soil water potential (ψ), instead of as a function of soil water content (θ). Either form can be used, because potential and water content are convertible using the water retention curve. However, given that tensiometer data are used for hydraulic gradient, it was deemed more consistent to estimate unsaturated hydraulic conductivity using the potential form of the equation. The method of calculation described above used data that were collected in the field or data obtained through laboratory studies. The only source of estimation was the relationship between hydraulic conductivity and water potential, but the form of Equation (2) has been used extensively by researchers and modelers for close to 20 years, and so it is a somewhat standard approach. The results should provide a realistic, yet indirect estimate of flux that could be occurring at the site.

B. Water Quality Analyses

To date, a total of 40 samples have been collected from the solution samplers installed beneath the trenches (16 samples total), or the monitoring boreholes (24 samples total) located to the north of slit trench #2. Most the samples were analyzed for Cs^{137}, H^3, K^{40}, and total activity. Table 3.2 lists the results for tritium only.

Results indicate elevated tritium concentrations toward the northern portion of the slit trench area, especially in shallower soils sampled in Boreholes 5 and 6. Results from Sampler #AT-5-23 yielded the highest tritium levels, all of which were close to or slightly above 1×10^5 pCi/L.

C. Flux Results

The K_{sat} data used for estimating unsaturated conductivity were measured by Law Engineering (1999) from samples taken at 6.4-m and 12.5-m depths. The n and m parameters fitted to Equation 1 are listed in Table 2.1. Estimated unsaturated hydraulic conductivity values, listed in Table 3.1, were obtained using these data and parameters. The results show some differences in conductivity values between depths, but very little scatter within depths (i.e., same depth, different boreholes). Estimated values at 6.4-m depth (21 ft) are lower than those from 12.5-m depth because of the higher α parameter in the van Genuchten equation, causing internal drainage to occur at higher potentials (less negative), and a consequently larger decrease in conductivity.

Table 3.2 lists the average hydraulic gradient and the coefficient of variation using three tensiometers in each borehole. The values are consistently close to unity; in such a case, assuming unit gradient throughout the profile is a reasonable assumption, and it allows us to estimate the flux using the unsaturated hydraulic conductivity directly, estimates of which are found in Table 3.1. Therefore, we can compare the results in Table 3.1 to other estimates of recharge at the site. One commonly used method for estimating recharge is to assume that a percentage of total precipitation infiltrates below the evaporative or transpirative depth of plants.

This was done by Cook (1999) on a previous PA calculation at the slit trenches. He assumed that 0.4 m/yr (0.11 cm/d and ~ 15 in/yr) of fluid would percolate the soil and cause radionuclides to migrate toward the water table. The estimated flux values used herein for the 6.4-m depth are very similar to those of Cook (1999), except that these estimates were based on data collected at the site using the monitoring system.

The product of the fluid flux values and the tritium concentrations is the mass flux of tritium that can be expected to migrate away from the disposal area and toward the water table. Thus, using the dimensions of the slit trenches (30 m wide by 200 m long) and the average flux value calculated for the 6.4-m depth (0.147 cm/d, or 1.47×10^{-3} m/d), an estimated volume of water percolating the trench area would be 3227 m^3/yr (or 8.8 m^3/d). Using the highest measured concentration of tritium as a conservative (worst-case) value (e.g., 1.06×10^5 pCi/L from AT-5-23 collected on 1/4/00), the total mass of tritium that could migrate away from the disposal area would be 0.342 Ci/yr, or about 35% of the 0.983 Ci/yr needed to exceed the MCL at a receptor well 100 m downgradient of the site (Cook, 1999).

4. Summary

The flux values – both fluid and tritium mass – were obtained using VZMS data collected at the E-Area disposal site during the last four months of 1999. Laboratory analytical data were limited to saturated hydraulic conductivity, soil water retention curves and tritium concentrations. All other data were obtained using monitoring sensors interrogated with remote data loggers, which are continuously powered with solar cells. Little to no maintenance of the sensors was needed during the monitoring period, illustrating that subsurface data is obtainable with only a small level of staff effort. The data were used to show that 1) steady-state conditions in the subsurface generally have been attained, 2) near-unit gradient conditions dominate from approximately 3.4-m to 16.2-m, and 3) tritium mass loading is below the threshold set from the Performance Assessment methodology.

A few additional points could improve the data collection and accuracy:

1. Solution samplers - Current procedures for collection of pore water samples involve imposing a vacuum on the samplers for extended time periods, sometimes on the order of several days or longer. Though no harm should come to the samplers by taking this approach, readings from the tensiometers and WCRs appear to be affected for long-time periods, requiring more time for the sensors to re-equilibrate with the soil water conditions. Unless large volumes of water are needed for chemical analysis, it is recommended that vacuum be imposed on the solution samplers for the minimum time necessary to collect enough water for chemical analysis. This should reduce the time necessary for re-equilibration of the sensors.

2. Depth of sensor installation - The depths of installation for the monitoring clusters is too deep to detect changes in near-surface soil water conditions, even when relatively frequent precipitation events occur at the site. Though the current depths were useful for estimating the downward flux of water, shallower sensors could also be used for monitoring surface conditions, where much of the water movement and atmospheric exchange occurs. Future installation of monitoring clusters closer to ground surface should be considered, especially after the slit trenches are covered with a low-conductivity cover. Direct monitoring of the cover conditions would enhance the estimates of flux.

3. Use of neutron probe - The neutron probe method should be used as a standard tool for long-term monitoring of the site. Though the ATs and WCR sensors have been shown to be useful in the short term, their lifespan has not been evaluated. Thus, while the monitoring clusters are operational, the neutron probe should be used to augment the existing data base, so that correlations can be made between the neutron probe readings and the sensors used to support the monitoring clusters. If sensors begin to fail, the neutron probe will become an invaluable tool for observing potential changes in soil water content.

5. References

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Table 2.1 van Genuchten parameters from fitting Equation 1 to retention data on samples collected at 6.4-m and 12.8-m depths.

Parameter	6.4-m depth	12.8-m depth
θ_s	0.379	0.361
θ_r	0.172	0.140†
α	0.034	0.020
n	1.742	1.881
m‡	0.426	0.468

† - parameter not fitted

‡- m = 1-1/n

Table 3.1 Tritium concentrations (pCi/L) from pore water samples collected beneath or adjacent to the slit trenches.

Location	7/1/99	9/13/99	11/08/99	1/4/00
SL1	3990	4540	4710	4330
SL2	1080	980	1420	1940
SL3	2100	2800	2420	5700
SL4	3340	3210	3340	3800
AT-5-23†	84000		105000	106000
AT-5-33	29700		28700	25100
AT-5-42		14100		
AT-5-57	12700	30700	13600	11400
AT-6-24			28200	
AT-6-43	13300	13300	12500	13600
AT-6-55	12400		12600	11800
AT-7-23		2220		
AT-7-42		7360	7480	8090
AT-7-54				7000

† Location designation: AT-X-YY, where X is borehole number, YY is depth (ft)

Table 3.2 Estimated unsaturated hydraulic conductivity values corresponding to measured water potentials at 6.4-m and 12.5-m depth.

Boring	Water Potential†		Hydraulic cond.	
	------ cm -----		-----cm/d----	
	6.4 m	12.5 m	6.4 m	12.5 m
5	-162.5	-128.5	0.12	8.58
6	-97.6	-118.2	0.19	9.34
7	-141.8	-132.9	0.13	8.28

† - average water potential taken from DOY 340 - 360 (6 - 26 Dec 99)

Table 3.3 Calculated hydraulic gradients in three boreholes from DOY 340 - 360 (6 - 26 Dec 99).

Boring	Avg. Hydr. Gradient		Coefficient of variation†	
			---------- % ----------	
	6.4 - 9.8 m	9.8 -12.5 m	6.4 - 9.8 m	9.8 -12.5 m
5	1.05	0.81	1.65	2.38
6	1.15	0.97	2.31	1.99
7	1.03	0.97	0.69	0.43

† - CV = Std Dev/Avg

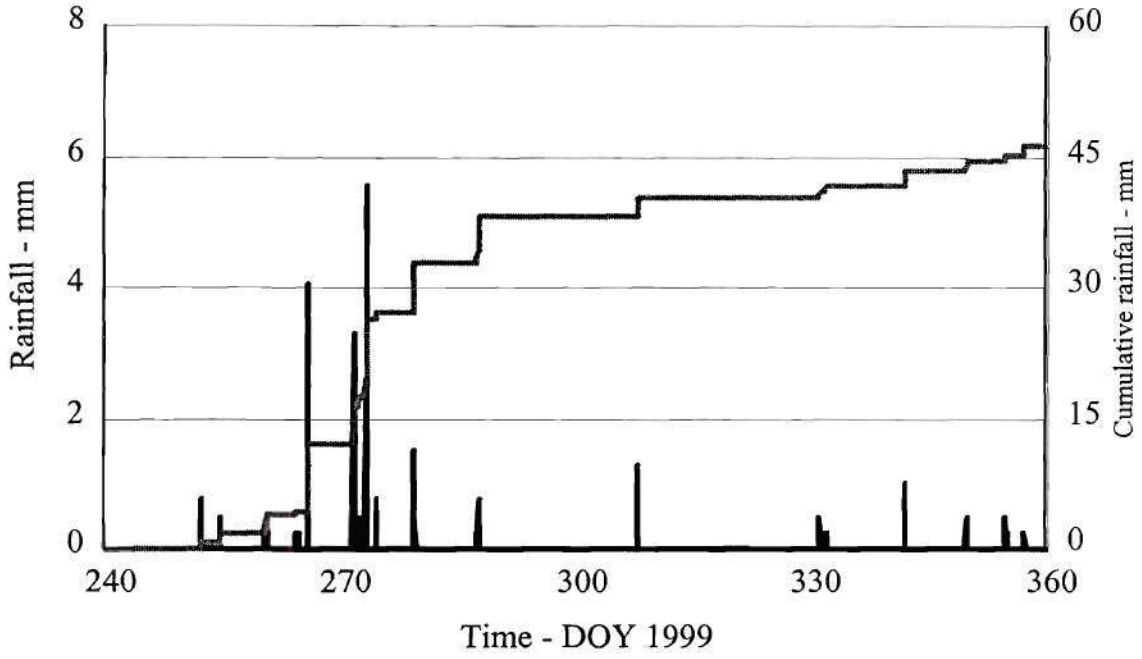

Figure 2.1 Precipitation recorded from tipping bucket rain gauge at Logger 5.

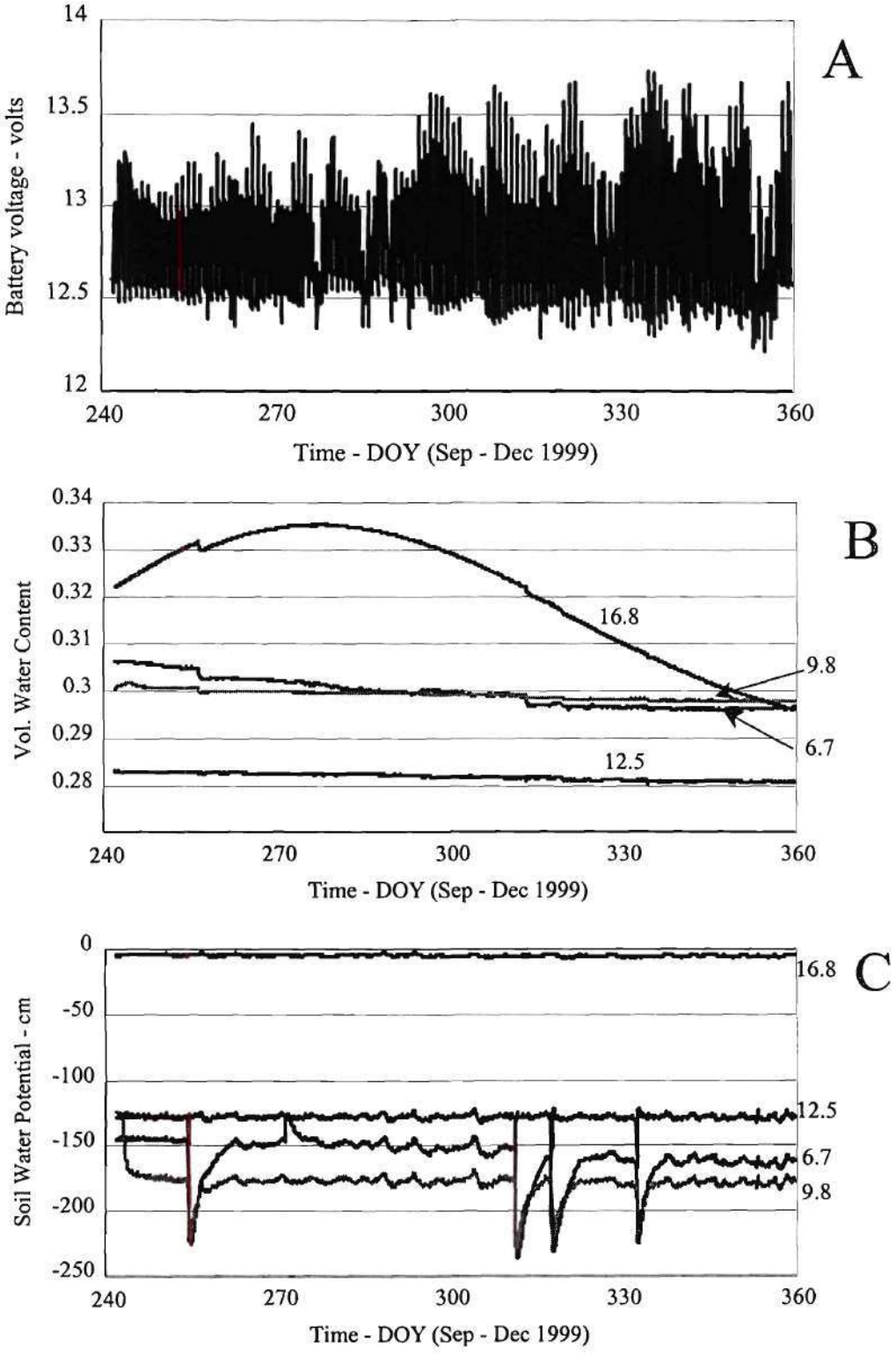

Figure 2.2 Battery voltage (A), soil water content (B), and soil water potential (C) recorded at Logger 5 from 1 Sep - 31 Dec 99. Numbers on graphs represent depth of sensor installation.

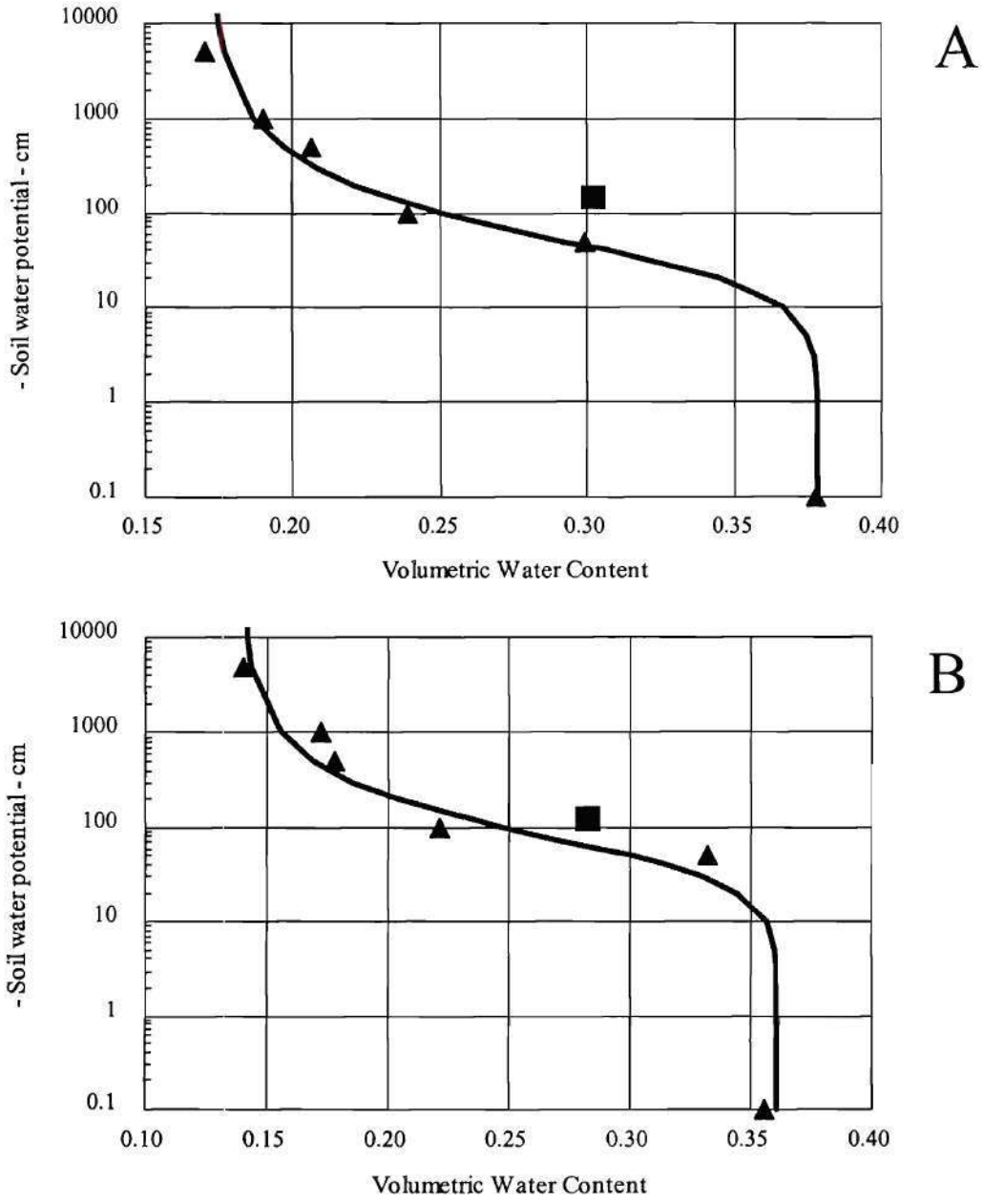

Figure 2.3 Soil water retention curves (triangles = measured data, lines = fitted) for soil samples collected at 6.1 m and 12.5 m depths, Graphs A and B, respectively. Single square on each graph represents a paired value of soil water content versus soil water potential collected using the VZMS sensors on DOY 270 (27 Sep 99).

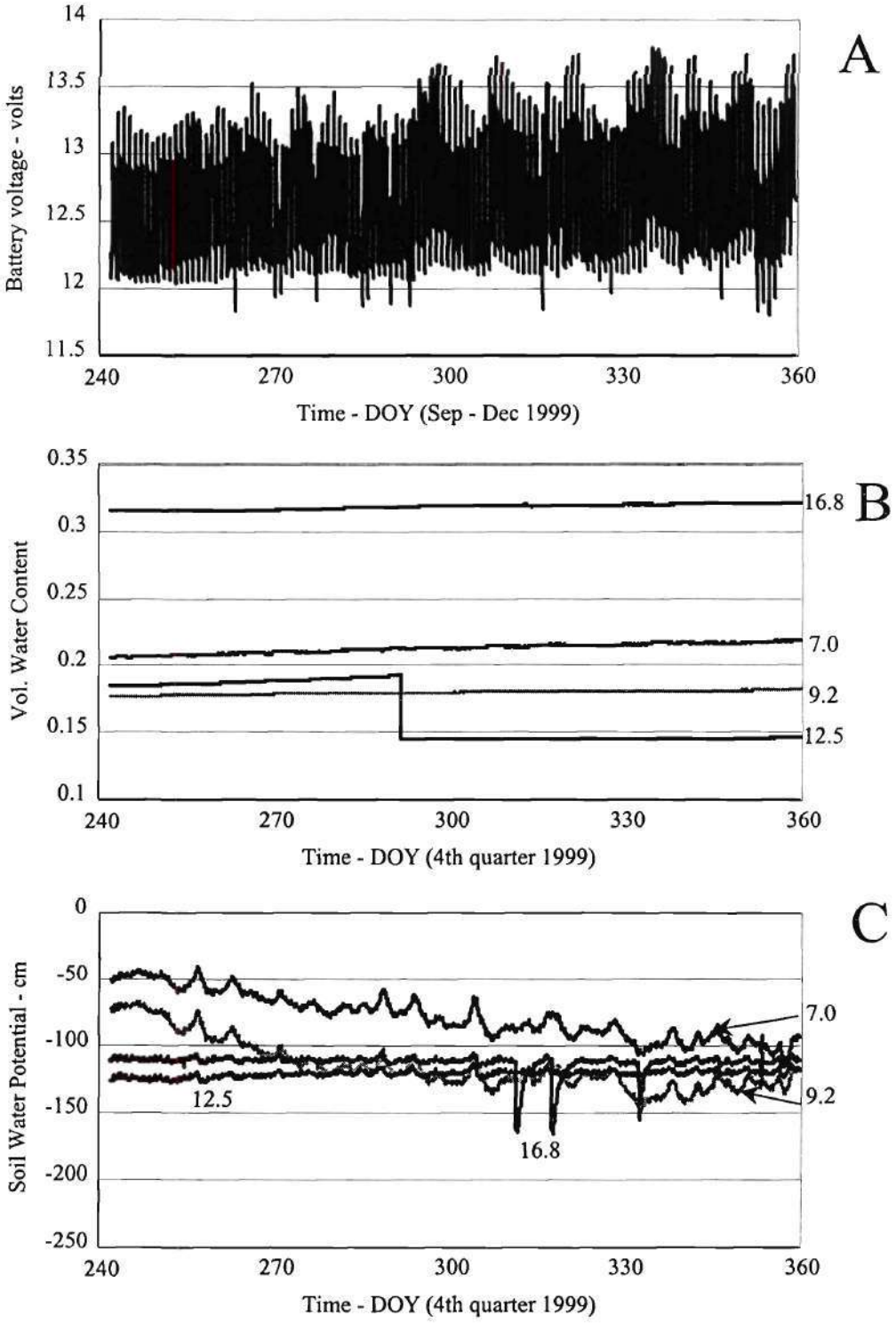

Figure 2.4 Battery voltage (A), soil water content (B), and soil water potential (C) recorded at Logger 6 from 1 Sep - 31 Dec 99. Numbers on graphs represent depth of sensor installation.

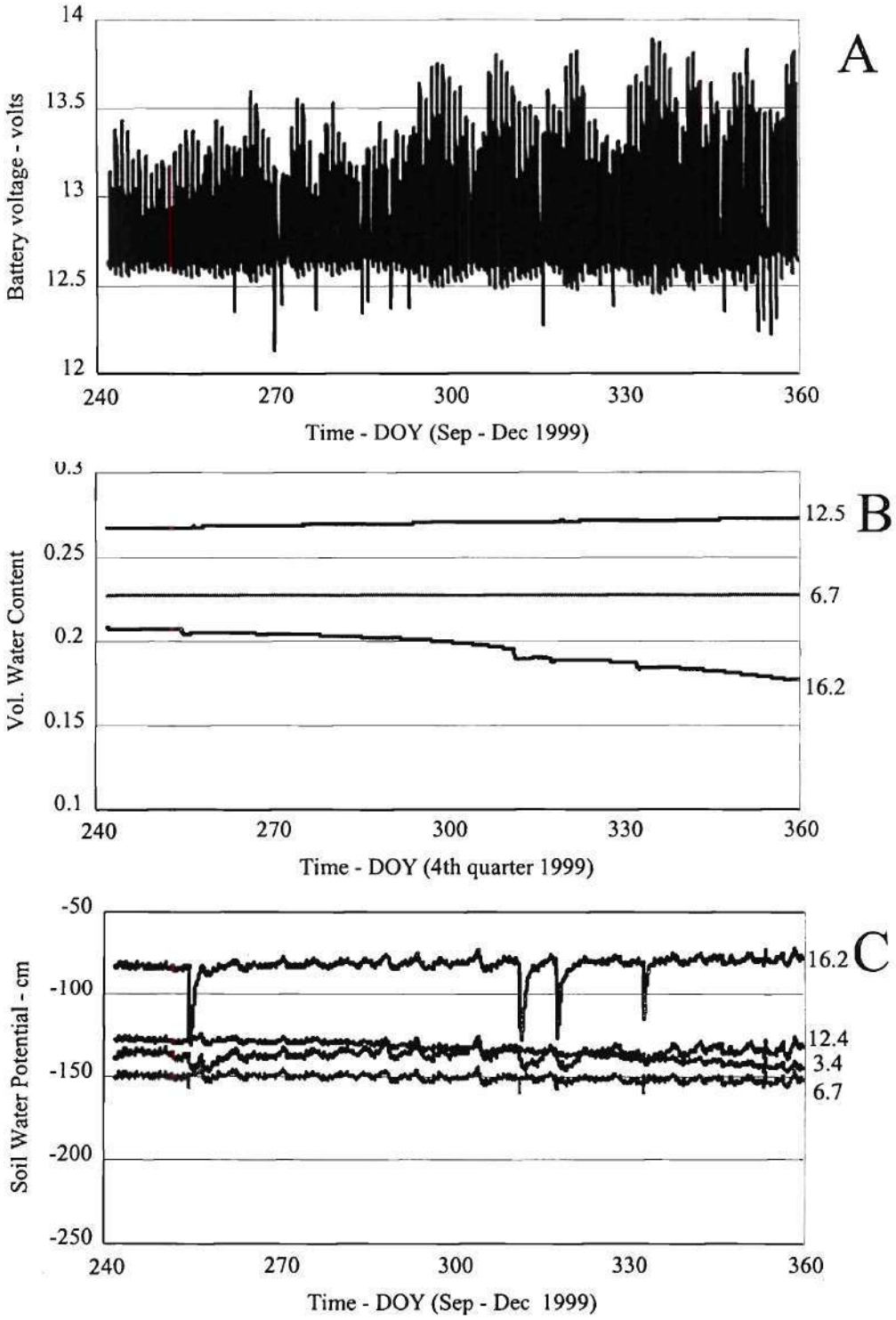

Figure 2.5 Battery voltage (A), soil water content (B), and soil water potential (C) recorded at Logger 7 from 1 Sep - 31 Dec 99. Numbers on graphs represent depth of sensor installation.

VADOSE ZONE MONITORING SYSTEM DEPLOYMENT(U)

Task 5 Report - Final

Evaluation of Data from the Vadose Zone Monitoring System: E-Area Disposal Facility

Contract No.: KE56201-0-GA0052
Georgia Tech Project No.: E-20-F39

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1. Introduction

A Vadose Zone Monitoring System (VZMS) was deployed in early 1999 to provide data and information about possible downward flux of water and contaminants emanating from the E-Area Disposal Facility trench area at the Savannah River Site (SRS), which could potentially contaminate ground water. The VZMS consists of monitoring sensors installed in clusters at four depths in each of three boreholes. The sensors measure subsurface conditions including soil water potential, soil water content and pore water concentration. Four other boreholes are equipped with devices that sample soil pore water only. Soil water content and water potential data have been collected continuously from installation through the present, and soil pore water samples were collected periodically.

This document is a follow-up from a deliverable submitted to the Educational Research and Development Agency (ERDA) which presented calculations of potential water flux through the soil material at the slit trenches at the E-Area disposal facility (Young, 1999). The document subsequently was forwarded to Ms. Heather Holmes-Burns (DOE/BNFL), the Task Order Representative for that contract (GA 0047). The purposes of this letter report are to 1) evaluate the behavior of the monitoring sensors used to support the existing VZMS, and 2) calculate estimates of water flux using VZMS data and hydraulic property data obtained from soil samples collected at the site and analyzed in the laboratory. This report describes the approach for the flux analysis.

Evaluation of monitoring data will focus primarily on data collected during a four-month period from September 1 - December 31, 1999. Data collected during earlier time periods will be discussed as appropriate; however, given that the hydrologic system and sensors were equilibrating, the data were not necessarily representative of long-term field conditions. Data collected during the last four months of 1999 appear to more closely represent the field conditions.

2. Data Analysis

The current VMZS consists of 3 data loggers, numbered 5 through 7, each operating four tensiometers (ATs), four water content reflectometers (WCRs), and four pore water samplers. Logger 5 also operates a tipping-bucket raingauge, calibrated so that one tip represents 0.25 mm (0.01 inch) of rainfall. Temperature and battery voltage data from each logger are stored for informational purposes. Data are stored hourly for all sensors. This portion of the report will describe the results from each logger individually.

A. Logger 5

Figure 2.1[1] shows precipitation recorded using the tipping-bucket raingauge. Hourly and cumulative amounts are shown. During the four-month time period described in this report, a total of just below 46.3 mm (1.82 inch) of precipitation occurred, with the bulk of that amount recorded on 23 September (7.62 mm) and 29-30 September (14.48 mm). With the close proximity of the other loggers to Logger 5 and to the slit trenches, these amounts are representative of rainfall that occurred at the slit trench site.

Figure 2.2A shows battery voltage levels oscillating between approximately 12.5 and 13.5 volts. Increasing the resolution of the graph shows daily highs during the afternoon and daily lows during the early mornings (graph not shown). Given that the battery voltage was greater than 11 volts, the power system for Logger 5 is more than sufficient to source current needs for the pressure transducers mounted on the ATs and for the WCR units.

Figure 2.2 B presents soil water content showing data from four depths. The lines are marked accordingly, though similarities between the different depths tend to obscure individual responses near the end of the time series. Water contents from at 16.8 m (55 ft) depth show gradual changes, with the highest values recorded on DOY 277 (4 Oct 99), followed by a steady

[1] All figures and tables are found at back of report

reduction. Though ground water levels are not available, the smooth increase and decrease in water content is most likely to water level fluctuations. Very slight water level declines were recorded from the other three probes, but the values themselves were highly repeatable. Several exceptions can be identified on DOY 256 (13 Sep 99), 313 (9 Nov 99), and 334 (30 Nov 99). Each of these days correlate with sampling events from the solution samplers, which took place two days earlier. The data show that hydraulic communication exists between the WCR and the solution samplers

Figure 2.2 C shows soil water potential for Logger 5. The data are marked by steady readings, interrupted by sampling events from the solution samplers that clearly alter the soil water potential readings for several days. Data collected from 16.8-m (55 ft) depth indicate the presence of the water table, capillary fringe, or some other feature that caused near saturation of water at the tensiometer cup. The subsurface condition should be confirmed using nearby monitoring wells, or possibly neutron probe data. Lack of saturated soil could indicate a possible leak in the tensiometer cup, with the pressure transducer providing offset readings only. The minor fluctuations, which are generally hidden due to resolution of the graph appear to show periodic behavior with a period length of 12 hours, amplitude of 2 cm, and with maximums occurring at 10:00 am and 10:00 pm. These values are consistent with the semi-diurnal behavior of earth tide loading from atmospheric heating and cooling (Miller and Thompson, 1979). The observed amplitude of 2 cm should not create uncertainties in the ability of the tensiometer to detect significant changes in soil water potential.

The shallow sensors did not detect any changes in water content or water potential caused by precipitation events during this monitoring period, as the upper soil layers replenished the soil water deficit that had developed during the summer months. The deficit increases the buffering capacity of the soil, reducing deeper responses caused by precipitation events. For example, if we assume that all 45 mm of precipitation occurred instantaneously (e.g., no evapotranspiration between events), an increase of 10% volumetric water content would be distributed with the upper 0.45 m of soil, much too shallow to be detected with the monitoring sensors installed at 6.7-m depth. Though water will redistribute vertically downward with time, an instantaneous

pulse of water input would be dissipated prior to reaching 6.7-m depth. Based on the available data, it appears that the current configuration of sensors will monitor deep soil water conditions only. If data on shallower conditions are needed to support an additional goal of the VZMS, then additional sensors would be needed.

Using data obtained from Shelby tube samples and analyzed for water retention characteristics, the paired values of water content and water potential can be fitted to a closed-form equation that describes the complete water retention curve, as shown by Equation (1) (van Genuchten, 1980):

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{(1+(\alpha\psi)^n)^m} \quad (1)$$

where θ_s is the saturated water content, θ_r is the residual water content, ψ is the soil water potential (L), and α, n, m are fitting parameters. Note that m is taken as m = 1-1/n. Figures 2.3A and B show the water retention curves for soil collected in Shelby tubes from 6.4-m and 12.5-m depths, respectively, adjacent to Logger 5. Data in Table 2.1 list the van Genuchten parameters. Included with each graph is a single data point taken from DOY 270, (27 Sep 99, 00:00 am). In both cases, the data point plots above the fitted retention curve, indicating an overestimation in either the water potential or water content, depending on which value is considered to be the "true" value (e.g., data with no bias or other error). If, for example the soil water potential is considered to be true value, then the water content could be overestimated by as much as 30% (equivalent to a water content of 0.07 cm^3/cm^3). If the water content is true, then the soil water potential would be about 1/3 of that measured with the tensiometer. Differences between the paired values of water potential and water content, from those obtained from the laboratory retention data, could be caused by several factors, including 1) spatial variability of soil properties between the sensors and the location of the Shelby tube samples, 2) disturbance of the soil sample during collection, or 3) a combination of the two, to name just a few.

Overall, data collected from the VZMS at Logger 5 appears to be in equilibrium with the soil, and appears to follow patterns expected of near-steady state conditions. Data loss due to instrument failure at this site has not occurred, but some of the soil water potential measurements

were affected by the long-term depressurization of the solution samplers. Shorter sampling events would prevent some of the loss of usable data from the tensiometers.

B. Logger 6

Figure 2.4 A shows the battery voltage for Logger 6. Power was maintained within the 12 - 13.5 volt range for virtually the entire monitoring period. The small dips in voltage below 12 volt occurred during a single collection event and the voltage returned thereafter. The power system appears to be operational and sufficient to power the logger and subsurface sensors.

Figure 2.4 B shows the soil water content from depths as listed on the figure. Similar to the sensor response from Logger 5, the readings were found to be highly repeatable. The general pattern of highest water content values at the bottom of the borehole, lowest values at 12.5 m depth, and intermediate values from the shallower sensors was identical to those found from Logger 5. However, it was noted that the overall readings, with the exception of the sensor at 16.8 m (55 ft) depth, were generally lower in magnitude than those collected from Logger 5, several meters away. Without textural data from each specific borehole, it is not possible conclude whether differences in water content are texturally controlled between the two boreholes, or whether the sensor data are systematically biased.

Very little variability between readings were recorded for any single WCR sensor, with the exception of the sensor installed at 12.5-m (41 ft) depth. Beginning on DOY 291 (18 Oct 99, 16:00), the sensor reading dropped from 0.192 to 0.145, and maintained the lower water content level throughout the remainder of the monitoring period. The raw data from the WCR revealed a decrease in the electromagnetic travel time down the probe, so the sensor response did, if fact, shift. No other sensors experienced a similar change in reading, and voltage levels were stable at the time. To the knowledge of the author, no other site activities occurred on that day. Therefore, either the sensor partially lost contact with the borehole wall or the sensor calibration suddenly shifted. It may be possible to check whether the former explanation has occurred by placing the solution lysimeter under high vacuum and observing the response of the WCR

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Fluid flux values, potentially containing radionuclides, are used as input to computer models by SRS personnel during their Performance Assessment (PA) modeling activities to evaluate whether the mass of tritium released from the site will exceed the Maximum Concentration Limit (MCL) of 20,000 pCi/L at a hypothetical receptor well located 100 m downgradient from the site.

This section provides an estimate of fluid flux using data obtained from the VZMS, and mass flux using tritium concentration data obtained from the solution samplers. The approach taken herein is similar to that used by Young (1999), where the parameters from the retention curve are used in the Mualem form of the hydraulic conductivity equation (Mualem, 1976):

$$K(\psi)=K_{sat}\frac{\left(1-(\alpha\psi)^{n-1}[1+(\alpha\psi)^{n}]^{-m}\right)^{2}}{[1+(\alpha\psi)^{n}]^{m/2}} \qquad (2)$$

where K_{sat} is the saturated hydraulic conductivity, measured in the laboratory, and α, m and n are fitting parameters determined from fitting retention data to Equation (1). The hydraulic gradient was calculated using soil water potential data collected with VZMS sensors in each of the three boreholes using $\Delta\psi/\Delta z = (\psi_1-\psi_2)/(z_1-z_2)$, where 1 and 2 are depth indices, increasing with depth. The fluid flux is determined using:

$$q = -K(\psi)\frac{dH}{dz} = -K(\psi)\frac{d}{dz}[\psi + z] \qquad (3)$$

where q is flux (L/T), and H is total head consisting of soil water potential ψ and gravitational z components (L). Depth increases downward so that a positive quantity in q means flux in the downward direction.

The hydraulic conductivity equation was written as a function of soil water potential (ψ), instead of as a function of soil water content (θ). Either form can be used, because potential and water content are convertible using the water retention curve. However, given that tensiometer data are used for hydraulic gradient, it was deemed more consistent to estimate unsaturated hydraulic conductivity using the potential form of the equation. The method of calculation described above used data that were collected in the field or data obtained through laboratory studies. The only source of estimation was the relationship between hydraulic conductivity and water potential, but the form of Equation (2) has been used extensively by researchers and modelers for close to 20 years, and so it is a somewhat standard approach. The results should provide a realistic, yet indirect estimate of flux that could be occurring at the site.

B. Water Quality Analyses

To date, a total of 40 samples have been collected from the solution samplers installed beneath the trenches (16 samples total), or the monitoring boreholes (24 samples total) located to the north of slit trench #2. Most the samples were analyzed for Cs^{137}, H^3, K^{40}, and total activity. Table 3.2 lists the results for tritium only.

Results indicate elevated tritium concentrations toward the northern portion of the slit trench area, especially in shallower soils sampled in Boreholes 5 and 6. Results from Sampler #AT-5-23 yielded the highest tritium levels, all of which were close to or slightly above 1×10^5 pCi/L.

C. Flux Results

The K_{sat} data used for estimating unsaturated conductivity were measured by Law Engineering (1999) from samples taken at 6.4-m and 12.5-m depths. The n and m parameters fitted to Equation 1 are listed in Table 2.1. Estimated unsaturated hydraulic conductivity values, listed in Table 3.1, were obtained using these data and parameters. The results show some differences in conductivity values between depths, but very little scatter within depths (i.e., same depth, different boreholes). Estimated values at 6.4-m depth (21 ft) are lower than those from 12.5-m depth because of the higher α parameter in the van Genuchten equation, causing internal drainage to occur at higher potentials (less negative), and a consequently larger decrease in conductivity.

Table 3.2 lists the average hydraulic gradient and the coefficient of variation using three tensiometers in each borehole. The values are consistently close to unity; in such a case, assuming unit gradient throughout the profile is a reasonable assumption, and it allows us to estimate the flux using the unsaturated hydraulic conductivity directly, estimates of which are found in Table 3.1. Therefore, we can compare the results in Table 3.1 to other estimates of recharge at the site. One commonly used method for estimating recharge is to assume that a percentage of total precipitation infiltrates below the evaporative or transpirative depth of plants.

This was done by Cook (1999) on a previous PA calculation at the slit trenches. He assumed that 0.4 m/yr (0.11 cm/d and ~ 15 in/yr) of fluid would percolate the soil and cause radionuclides to migrate toward the water table. The estimated flux values used herein for the 6.4-m depth are very similar to those of Cook (1999), except that these estimates were based on data collected at the site using the monitoring system.

The product of the fluid flux values and the tritium concentrations is the mass flux of tritium that can be expected to migrate away from the disposal area and toward the water table. Thus, using the dimensions of the slit trenches (30 m wide by 200 m long) and the average flux value calculated for the 6.4-m depth (0.147 cm/d, or 1.47×10^{-3} m/d), an estimated volume of water percolating the trench area would be 3227 m^3/yr (or 8.8 m^3/d). Using the highest measured concentration of tritium as a conservative (worst-case) value (e.g., 1.06×10^5 pCi/L from AT-5-23 collected on 1/4/00), the total mass of tritium that could migrate away from the disposal area would be 0.342 Ci/yr, or about 35% of the 0.983 Ci/yr needed to exceed the MCL at a receptor well 100 m downgradient of the site (Cook, 1999).

4. Summary

The flux values – both fluid and tritium mass – were obtained using VZMS data collected at the E-Area disposal site during the last four months of 1999. Laboratory analytical data were limited to saturated hydraulic conductivity, soil water retention curves and tritium concentrations. All other data were obtained using monitoring sensors interrogated with remote data loggers, which are continuously powered with solar cells. Little to no maintenance of the sensors was needed during the monitoring period, illustrating that subsurface data is obtainable with only a small level of staff effort. The data were used to show that 1) steady-state conditions in the subsurface generally have been attained, 2) near-unit gradient conditions dominate from approximately 3.4-m to 16.2-m, and 3) tritium mass loading is below the threshold set from the Performance Assessment methodology.

A few additional points could improve the data collection and accuracy:

1. Solution samplers - Current procedures for collection of pore water samples involve imposing a vacuum on the samplers for extended time periods, sometimes on the order of several days or longer. Though no harm should come to the samplers by taking this approach, readings from the tensiometers and WCRs appear to be affected for long-time periods, requiring more time for the sensors to re-equilibrate with the soil water conditions. Unless large volumes of water are needed for chemical analysis, it is recommended that vacuum be imposed on the solution samplers for the minimum time necessary to collect enough water for chemical analysis. This should reduce the time necessary for re-equilibration of the sensors.

2. Depth of sensor installation - The depths of installation for the monitoring clusters is too deep to detect changes in near-surface soil water conditions, even when relatively frequent precipitation events occur at the site. Though the current depths were useful for estimating the downward flux of water, shallower sensors could also be used for monitoring surface conditions, where much of the water movement and atmospheric exchange occurs. Future installation of monitoring clusters closer to ground surface should be considered, especially after the slit trenches are covered with a low-conductivity cover. Direct monitoring of the cover conditions would enhance the estimates of flux.

3. Use of neutron probe - The neutron probe method should be used as a standard tool for long-term monitoring of the site. Though the ATs and WCR sensors have been shown to be useful in the short term, their lifespan has not been evaluated. Thus, while the monitoring clusters are operational, the neutron probe should be used to augment the existing data base, so that correlations can be made between the neutron probe readings and the sensors used to support the monitoring clusters. If sensors begin to fail, the neutron probe will become an invaluable tool for observing potential changes in soil water content.

5. References

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Table 2.1 van Genuchten parameters from fitting Equation 1 to retention data on samples collected at 6.4-m and 12.8-m depths.

Parameter	6.4-m depth	12.8-m depth
θ_s	0.379	0.361
θ_r	0.172	0.140†
α	0.034	0.020
n	1.742	1.881
m‡	0.426	0.468

† - parameter not fitted

‡- m = 1-1/n

Table 3.1 Tritium concentrations (pCi/L) from pore water samples collected beneath or adjacent to the slit trenches.

Location	7/1/99	9/13/99	11/08/99	1/4/00
SL1	3990	4540	4710	4330
SL2	1080	980	1420	1940
SL3	2100	2800	2420	5700
SL4	3340	3210	3340	3800
AT-5-23†	84000		105000	106000
AT-5-33	29700		28700	25100
AT-5-42		14100		
AT-5-57	12700	30700	13600	11400
AT-6-24			28200	
AT-6-43	13300	13300	12500	13600
AT-6-55	12400		12600	11800
AT-7-23		2220		
AT-7-42		7360	7480	8090
AT-7-54				7000

† Location designation: AT-X-YY, where X is borehole number, YY is depth (ft)

Table 3.2 Estimated unsaturated hydraulic conductivity values corresponding to measured water potentials at 6.4-m and 12.5-m depth.

Boring	Water Potential†		Hydraulic cond.	
	------ cm -----		-----cm/d----	
	6.4 m	12.5 m	6.4 m	12.5 m
5	-162.5	-128.5	0.12	8.58
6	-97.6	-118.2	0.19	9.34
7	-141.8	-132.9	0.13	8.28

† - average water potential taken from DOY 340 - 360 (6 - 26 Dec 99)

Table 3.3 Calculated hydraulic gradients in three boreholes from DOY 340 - 360 (6 - 26 Dec 99).

Boring	Avg. Hydr. Gradient		Coefficient of variation†	
			---------- % ----------	
	6.4 - 9.8 m	9.8 -12.5 m	6.4 - 9.8 m	9.8 -12.5 m
5	1.05	0.81	1.65	2.38
6	1.15	0.97	2.31	1.99
7	1.03	0.97	0.69	0.43

† - CV = Std Dev/Avg

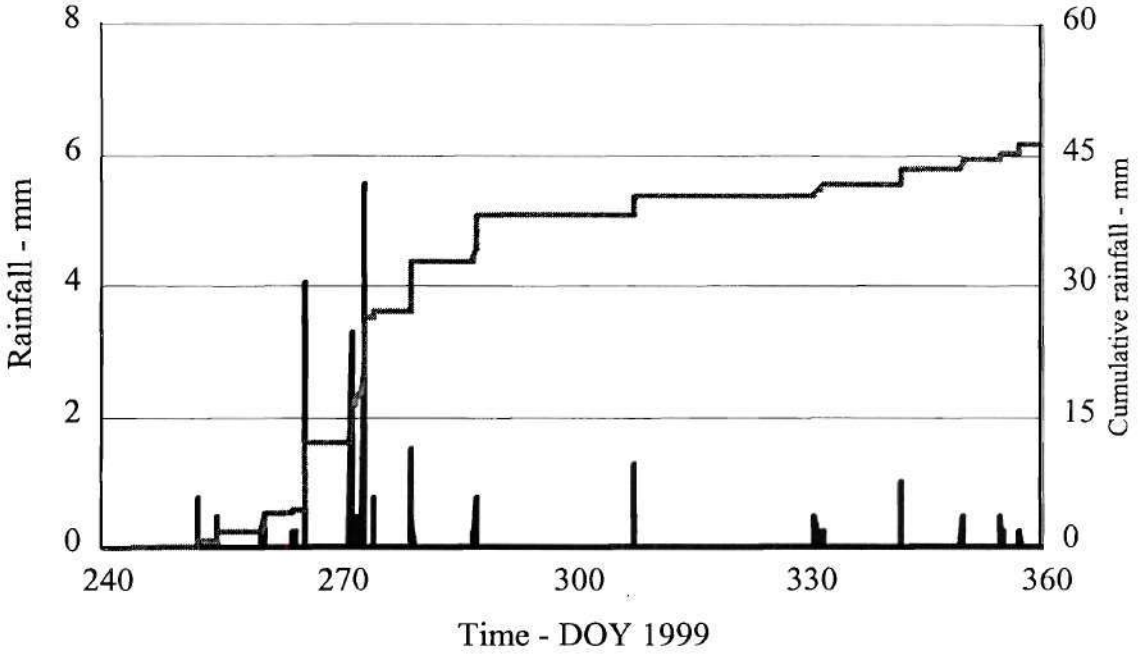

Figure 2.1 Precipitation recorded from tipping bucket rain gauge at Logger 5.

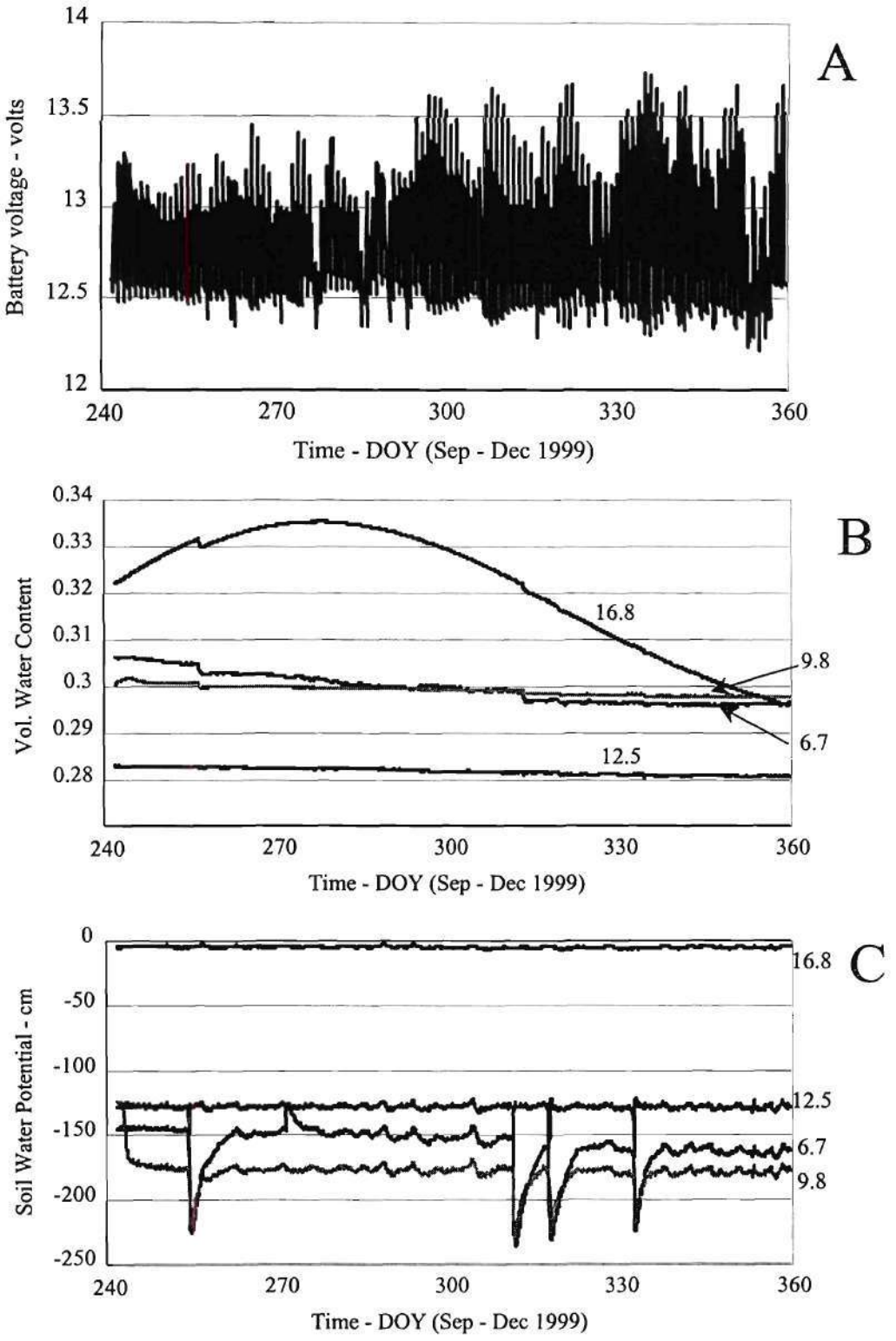

Figure 2.2 Battery voltage (A), soil water content (B), and soil water potential (C) recorded at Logger 5 from 1 Sep - 31 Dec 99. Numbers on graphs represent depth of sensor installation.

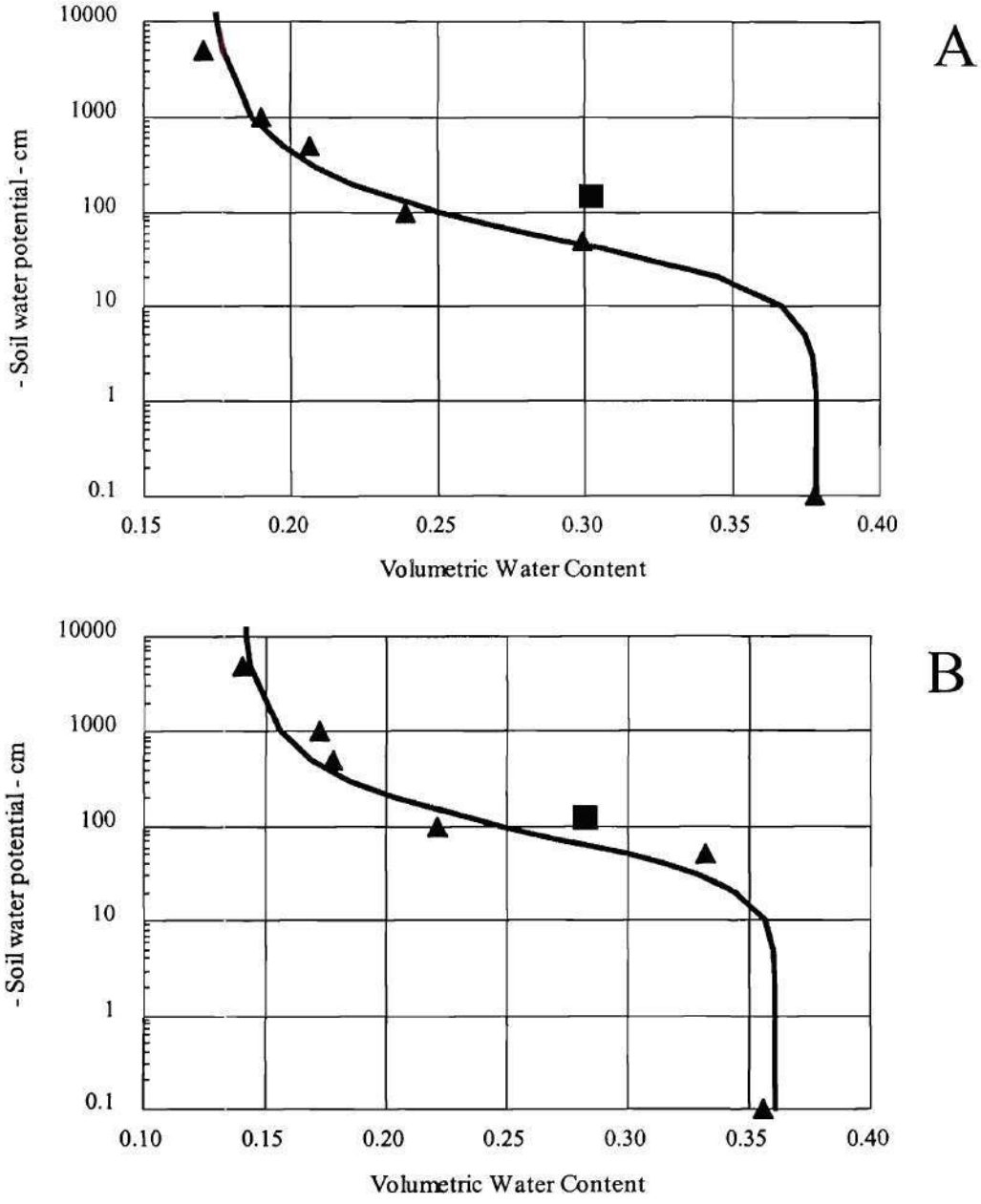

Figure 2.3 Soil water retention curves (triangles = measured data, lines = fitted) for soil samples collected at 6.1 m and 12.5 m depths, Graphs A and B, respectively. Single square on each graph represents a paired value of soil water content versus soil water potential collected using the VZMS sensors on DOY 270 (27 Sep 99).

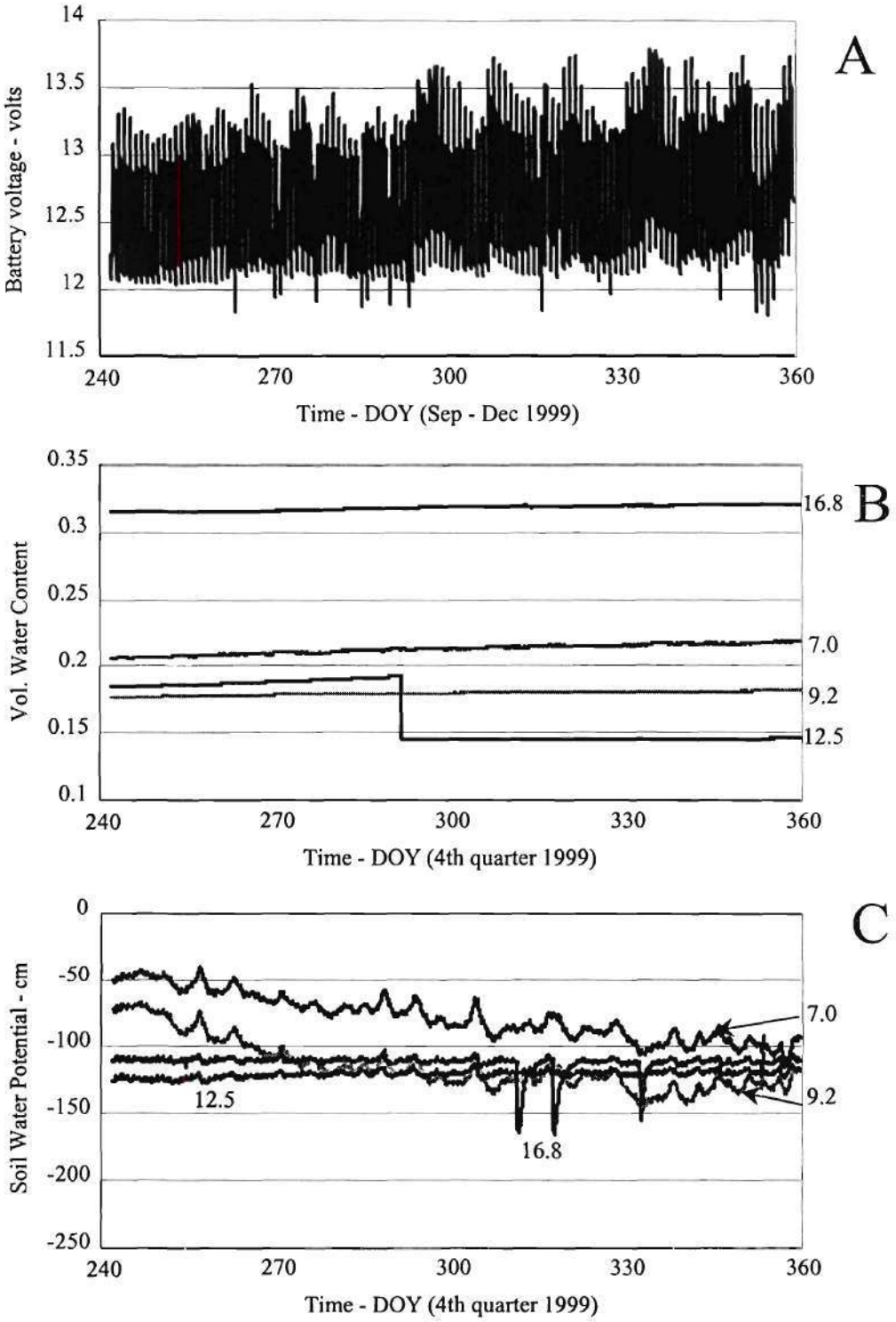

Figure 2.4 Battery voltage (A), soil water content (B), and soil water potential (C) recorded at Logger 6 from 1 Sep - 31 Dec 99. Numbers on graphs represent depth of sensor installation.

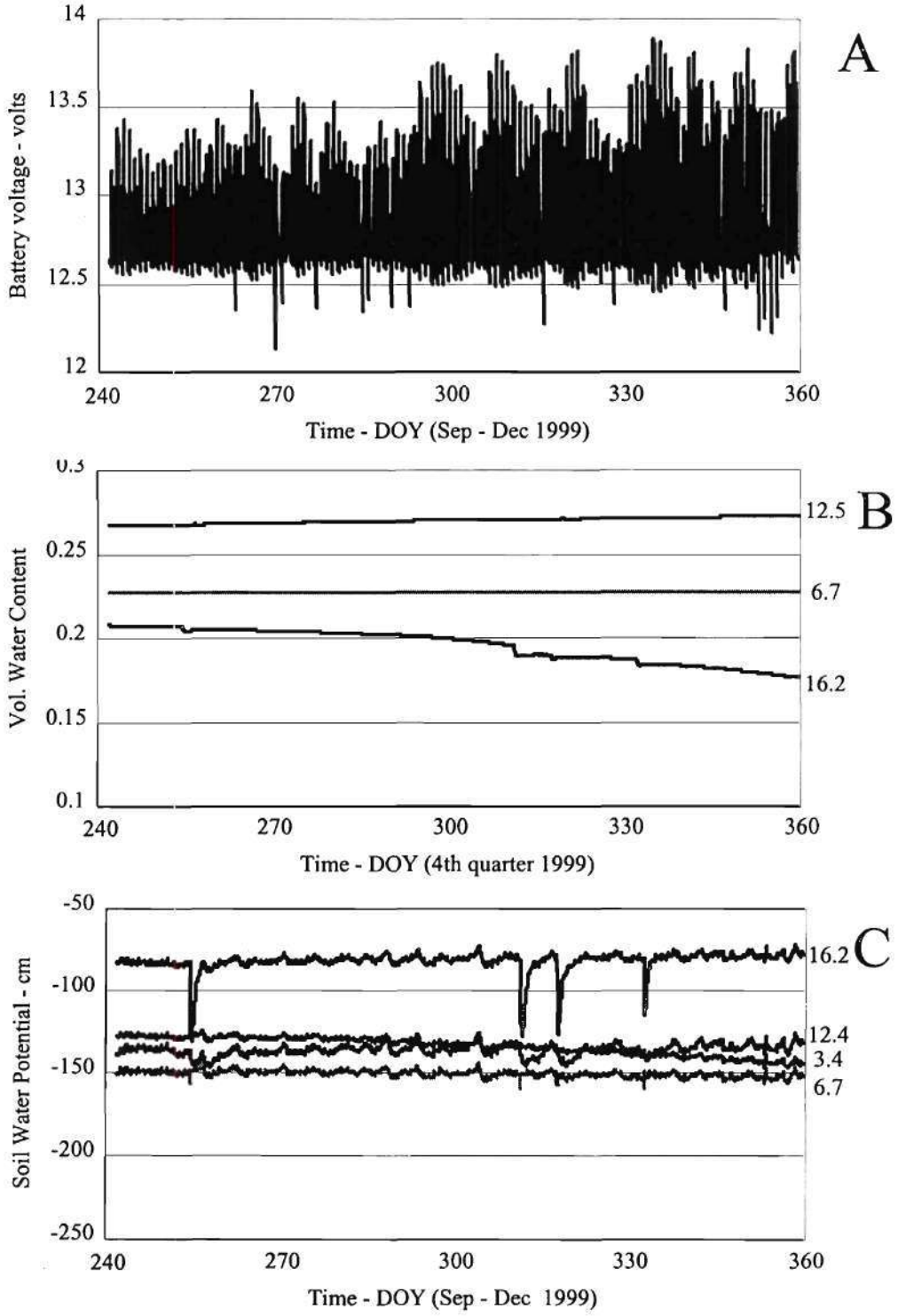

Figure 2.5 Battery voltage (A), soil water content (B), and soil water potential (C) recorded at Logger 7 from 1 Sep - 31 Dec 99. Numbers on graphs represent depth of sensor installation.